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In-house Report
July 1976

EVALUATION OF AN ENCLOSED WIRE BURIED LINE TRANSDUCER

Robert Falk
William F. Gavin, Jr.

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ROME AIR DEVELOPMENT CENTER
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This report describes preliminary field evaluation of an enclosed wire intrusion detection transducer. The main objective was to evaluate the response of the transducer to various stimuli and generate a data base of the signals from these stimuli for use in further investigations. Data were gathered on targets under various frost and snow ground conditions. Sensitivity measurements were made along the length of the transducer and repeatability measurements were made at single points along the transducer as well as along the length. Recommendations are presented for possible applications for this device, as well as for

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additional experimentation that should be completed.

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1.0 Introduction

1.1 Background

The use of electronic security systems to aid in the protection of critical Air Force resources has played an increasingly significant role in the past few years. In response to Air Force requirements, RADC initiated an exploratory development program under project 6515, task 13 entitled, "Ground Sensor Technology," to investigate problems associated with ground sensor surveillance. One of the prime areas of investigation under this program is the transducer with particular emphasis on the line transducer. Line transducers are usually passive devices which have long narrow fields of view and are sensitive to disturbances over their entire length (usually 300 to 400 feet). These types of transducers are currently used primarily in sensor systems providing security protection about the perimeter of fixed installations such as base perimeters, weapon storage areas, alert aircraft parking areas, etc. Development of buriable line sensors has only been moderately successful. Those that responded to seismic or pressure phenomena became insensitive in frozen ground which has been attributed to ice bridges and loose coupling. Some that respond to magnetic phenomena operated more effectively in frozen ground but required large trenches (7 feet wide x 2 feet deep x 300 feet long). Installation required heavy equipment to dig the trench and then backfill after the sensor had been installed.

This was both time consuming and expensive.

During 1974, an effort was initiated to investigate a relatively new line sensor proposed by the Westinghouse Electric Corporation for application to Air Force requirements. The transducer, called the enclosed wire-in-tube (WIT) transducer, appeared to offer significant technological promise over presently used line sensors. Theoretical considerations indicated that the sensitivity of the transducer, once installed, should not suffer any serious degradation under all possible terrain and weather conditions. Also, the transducer could be installed using a relatively inexpensive, simple, trenching machine. RADC entered into a contract with Westinghouse for the delivery of four breadboard models for field testing. The four transducers were installed in the ground at the RADC Sensor Data Acquisition Facility in October of 1974. The pre-amplifiers and processor/display console were delivered, installed and energized on 6 January 1975.

1.2 Objective

The objective of this report is to describe the test results that were obtained with the equipment delivered by Westinghouse. Included, where necessary, will be data collected by the contractor before delivery to RADC. This data will be used to supplement the data collected by RADC in order to provide a more complete understanding of the operating principle of the transducer, and its response to various stimuli.

The main objectives of the test program were to obtain an understanding of the operating principle of the transducer, obtain a signature data base on a variety of targets and non-targets, and make recommendations for future work required to develop this transducer into an operational sensor. The specific objectives of each test are documented in section 3.0 of this report.

2.0 Description of Sensor

2.1 Transducer and Theory of Operation

The WIT transducer consists simply of a hollow metallic tube with an insulated wire loosely laid within it. This forms a distributed capacitor whose nominal capacitance is significantly changed by a disturbance of the tube due to an intruder walking across the area containing the transducer. The wire, or inner conductor, consists of a standard 26 gauge wire with a teflon insulation. The tube, or outer conductor is standard 0.25 inch diameter copper tubing. The contractor has added a P.V.C outer jacket to reduce ground current concentration on the transducer from nearby power lines. The tube is purged with dry nitrogen gas to eliminate moisture and the ends are sealed. On the preamplifier end, a vacuum feed-through seal is used to connect the inner conductor to the preamplifier. Since the wire is loosely laid, it has randomly spaced touching points within the outer tube. The areas in proximity to each touching point are areas of high capacity and mechanical freedom which provide the sensitivity required to detect the capacitance change. These capacity changes are converted to voltage changes by biasing the wire with a high voltage. The voltage changes are amplified and processed by appropriate electronics. In our case, biasing is provided by the electret properties of the teflon insulation. An electret

is a material that is capable of containing trapped charges and the normal manufacturing process of teflon coated wire results in a trapped charge equivalent to several hundred volts of bias.

Westinghouse has determined three basic mechanisms for producing the change in the wire and tube relationship. The first is called the displacement mode and is a result of a slight bending of the tube from the depression of the earth as an intruder walks over the transducer. The signals generated in this mode are usually in the frequency band below 1 hertz. The second mechanism is termed the strumming mode. The impact of the foot on the ground causes the wire to vibrate or strum between touching points. The signals generated in this mode will normally fall within the 20 Hz to 100 Hz band. The third mode is an accelerometer mode resulting in frequencies from 100 Hz and up. For additional theoretical considerations the reader is directed to a paper[1] presented by Westinghouse at the 1974 Carnahan Conference and published in their proceedings.

2.2 Preamplifier

The preamplifier was designed to be directly connected to, and buried with, the transducer. It is housed in a stainless steel cylindrical container with a transducer connector

at one end and a permanently sealed multiconductor cable fed through the other end for power and signal lines. A photograph of this unit is shown in Figure 2-1. A schematic for the preamplifier is shown in Figure 2-2. The preamplifier has a fixed voltage gain of 40 dB and a band pass frequency that ranges from approximately .017 Hz to 10 KHz.

The FET input stage (Q_1 in the schematic) provides low noise characteristics as well as high input impedance. This provides an initial 20 dB of gain and the remaining 20 dB of gain is provided by the uA741 operational amplifier which also provides a low drive impedance for the next amplifier stage.

In addition to amplifying the incoming signal, the preamplifier can accept a test signal at its input so that the integrity of the preamplifier and processor/display console can be evaluated.

A more complete description of this unit can be found in appendix A of this report.

2.3 Processor/Display Console

The processor/display console was designed to process the signals from four transducers simultaneously. It contains a common power supply for the four amplifier channels and the display. A block diagram of one channel of this unit is shown in Figure 2-3. Only that portion of the circuit enclosed in the dotted lines was used for the collection of data and the

FIGURE 2-1. Preamplifier

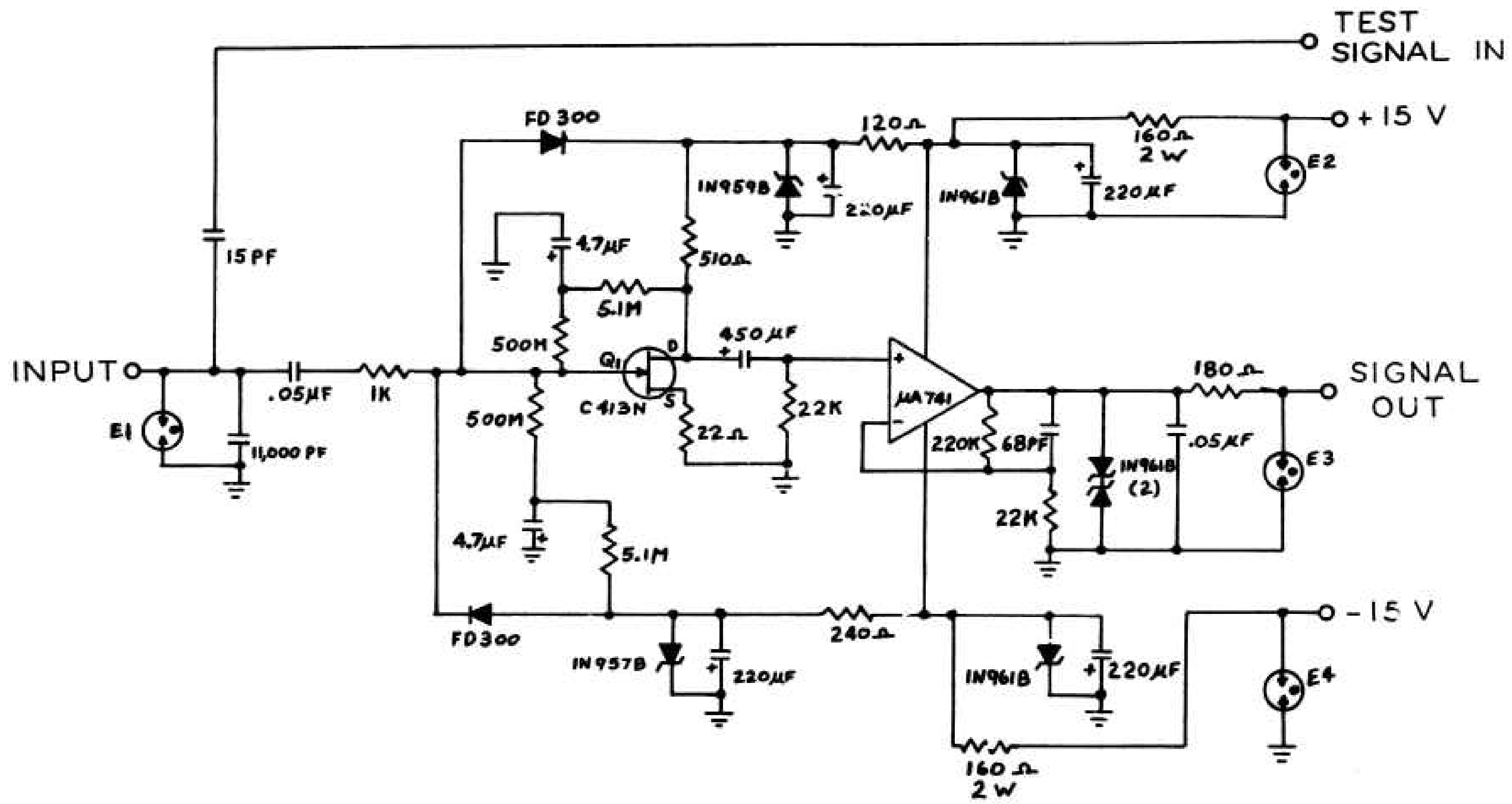

FIGURE 2-2. Wit Preamplifier Schematic

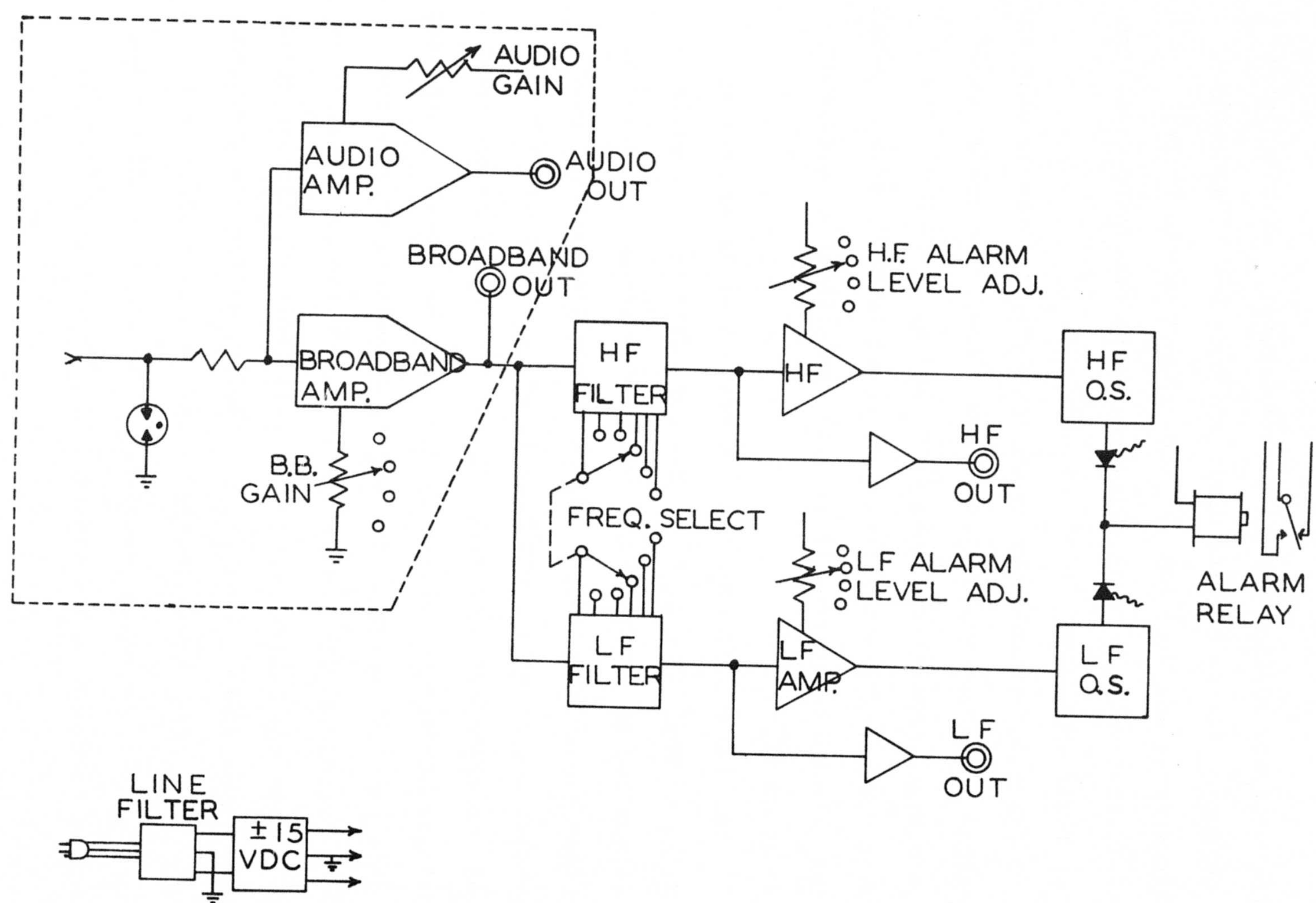

FIGURE 2-3. Block Diagram of Processor/Display Console

analysis of the performance of the transducer. At this point the broadband analog and the audio analog signals have only been amplified and have not yet been shaped by the filter sections that follow. A description of the remaining circuitry can be found in appendix A of this report.

The input signal from the preamplifier is fed to both the broadband amplifier and the audio amplifier. The bandwidth of the broadband amplifier ranges from .043 Hz to 54 KHz. The gain is resistor selected from 0 to 40 dB in 10 dB steps. Added to the gain of the preamplifier, this results in a total gain of 40 to 80 dB.

The audio amplifier has a bandwidth of approximately 66 Hz to 68 KHz. The gain of this amplifier is also 40 dB but is controlled by a gain potentiometer resulting in continuous adjustment over this range. Added to the preamplifier gain, the audio amplifier is continuously adjustable from 40 dB to 80 dB. A phone jack for each channel is located on the front panel for headset or speaker listening. The remaining segments of this unit all acted on the analog signals to provide some unique processing for analysis. These additional functions were provided by the contractor as analysis tools for the evaluation of this transducer. However, the additional functions of the electronics were not evaluated in this report since it was felt that the evaluation would be of the hardware and not the concepts intended by the contractor. The analysis facility

at RADC is capable of evaluating the concepts embodied in the hardware without being subject to the constraints and tolerances of the hardware design.

3.0 Experimental Objectives

In evaluating any transducer, certain characteristics provide an insight into not only the operation of the transducer itself, but also the potential of designing and developing a processor that would fully utilize the information from the transducer. Four basic parameters were chosen for investigation as a means of characterizing the transducer. These are sensitivity, repeatibility, stability, and frequency response. It cannot be overemphasized that the tests conducted and the responses received are only valid for the site at RADC and cannot be extrapolated to other areas without supporting data.

3.1 Sensitivity

The basic objective of the sensitivity experiments was to obtain an approximate figure for the detection range of an intruder. This can only be an approximation because footsteps are not repeatable events and even one intruder cannot maintain a consistent walk from intrusion to intrusion. However, it is still necessary to develop a sensitivity profile if one is to make a judgement of the potential usefulness of the device.

3.2 Repeatability

The basic objective of the repeatability experiments was to develop the data base necessary to make recommendations for the type or types of processing electronics that should be developed for the transducer. The results of these experiments would determine whether this device should be developed strictly as a listening device or have a simple logic. This will

depend heavily on a target providing almost the same signal from day to day.

Two aspects of repeatability must be assessed in order to make a determination of the type of processing to be developed. The first is to determine the repeatability of a signal at a single point. This would provide an insight into the settling of the wire within the tube after an intrusion. If repetitive loads at a single point result in repeatable signals then it can be concluded that the wire returns to its position before the load was applied. This would permit easier implementation of a signal processor. If the signals are not repeatable then the degree of change would determine whether the device should be used as a listening device or whether the change would be within the tolerances required for a signal processor.

The second aspect would be to determine the repeatability at various points along the line. One would not expect the results to be exactly the same because of the variation in electret potential along the line, variation in distance between touching points, variation in the seismic propagation channel, etc. The degree of variation will be a determining factor in the type of electronics that is recommended for future development.

3.3 Stability

The objective of this phase is to determine the effects of

environmental conditions on the performance of the transducer. In particular, frost and high winds have caused considerable problems with other line transducers. While the intention of this section was to concentrate on high winds and frost, other aspects of the environment were not overlooked. Signatures of rain, thunder, etc. were collected as part of the data base necessary for future developments. Some difficulties were experienced in meeting these objectives and are documented in section 6.3 of this report. Signatures of targets under a variety of environmental conditions will be collected as part of the data base.

3.4 Frequency Response

The objective of this aspect of the evaluation program is to determine the frequency content of both targets of interest and non-targets. This information is required also as a base in determining the type of processing that should be developed for this transducer. If the data indicates that pattern recognition principles should be applied to design and develop a classifier, then this information would form the initial data base necessary for that work.

4.0 Experimental Configuration

4.1 Test Field

The test area used for these experiments is designated RADC Sensor Data Acquisition Facility-Site 2D. It is located approximately 1,400 feet from the northwest end of the main runway at Griffiss Air Force Base. The 37.5 acre site is primarily a flat, grassy, open area with a stand of mixed trees on one segment of the site. It is used for the evaluation of intrusion detection sensors in a near operational environment. Permanently located at the site are the following:

a. Weather instrumentation.

b. A network of underground signal cables with field junction boxes.

c. Buried thermocouple trees and frost gauges.

d. Office-type trailers containing digital and analog data acquisition equipment.

A layout of the site is shown in Figure 4-1. Four transducers are buried at the positions shown. The procedure for burying the transducer was the following:

a. Dig a trench 10 inches deep and four inches wide and smooth the bottom of the trench.

b. Add 1 to 2 inches of sand and smooth over the bottom of the trench.

c. Lay the transducer on the sand and cover with 2 to 4 additional inches of sand.

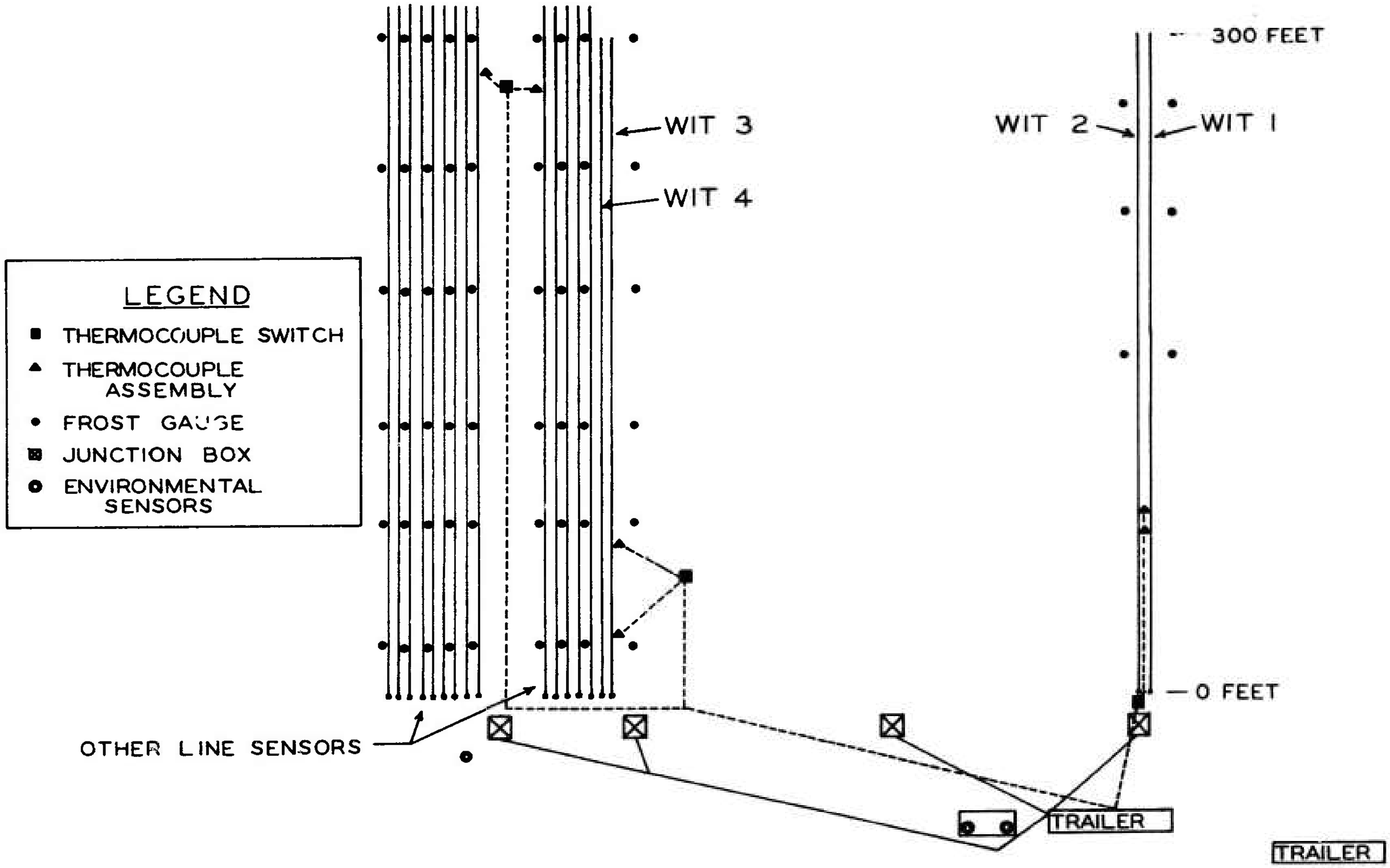

FIGURE 4-1. RADC Site 2D

d. Wet down the sand to insure elimination of voids between the transducer and the soil.

e. Backfill half of the remaining trench with the soil that was removed from the trench. Wet down with water and tamp. Backfill the remaining portion of the trench and tamp.

The soil at this site was analyzed by the U.S. Army Corps of Engineers, Cold Region Research and Engineering Laboratory, Hanover, New Hampshire.[2] Four soil borings were made on the site and water content and visual classification of the samples is shown in Table 1. Table II shows the dry density and thermal conductivity of the soil samples. Sieve and hydrometer analyses were conducted on three samples from one of the borings. The analyses indicate that the material becomes coarser with depth, contains significant amounts of silt and clay particles, and is frost susceptible. The conclusions drawn by these investigators are:

a. That ice lensing and concurrent heaving will accompany frost penetration due to the availability of ground water.

b. In the spring, the soil will become weak when thawing since it will be slow to drain and will contain excess moisture due to the melting of the ice lenses.

4.2 Recording Instrumentation

All information collected during these experiments was recorded from the analog and audio output jacks on the control circuit. At this point, the signals from the transducers are pure analog data and are recorded for later analysis. These

TABLE I

WATER CONTENT AND VISUAL CLASSIFICATION OF SOILS

BORING		1		2		3		4	
DEPTH (INCHES) FROM	TO	WATER* CONTENT	VISUAL CLASS	WATER CONTENT	VISUAL CLASS	WATER CONTENT	VISUAL CLASS	WATER CONTENT	VISUAL CLASS
1	6	31.4	BROWN CLAY	11.8	CLAY/ SHALE	33.6	CLAY	17.7	ROCKY CLAY
6	12	28.[illegible]	BROWN CLAY	16.8	CLAY/ SHALE	25.8	CLAY	20.6	ROCKY CLAY
12	18	22.4	BROWN CLAY	23.3	BROWN CLAY	18.8	ROCKY CLAY	24.8	ROCKY CLAY
18	24	30.4	BROWN CLAY	33.4	BROWN CLAY	18.5	ROCKY CLAY	20.6	ROCKY CLAY
24	30			15.4	ROCKY CLAY	17.2	ROCKY CLAY		
30	36			12.8	ROCKY CLAY	13.3	ROCKY CLAY		
36	42			12.9	ROCKY CLAY	17.0	ROCKY CLAY		
42	48					12.9	ROCKY CLAY		* % BY WEIGHT

TABLE II

DRY DENSITY OF SOIL

LOCATION	DEPTH (IN.)		VISUAL CLASS.	DRY DENSITY (PCF)	THERMAL CONDUCTIVITY *	
	FROM	TO			UNFROZEN	FROZEN
1	1	6	BROWN CLAY	86.0	0.7	1.1
1	15	21	BROWN CLAY	100.8	0.9	1.2
2	1	5	CLAY/SHALE	113.7	0.9	0.95
3	1	6	CLAY	84.2	0.7	1.2
4	1	5	ROCKY CLAY	98.5	0.7	0.95

* BTU-FT/FT^2-HR-°F

signatures are recorded on magnetic tape using a Honeywell Magnetic Tape Recorder, Model 5600. This has the capability of simultaneously recording fourteen (14) channels of analog information. The time code was recorded on one channel of the tape using an Eldorado Time Code Generator, Model 1730. Wind speed, wind direction, and temperature were also recorded on the tape using appropriate sensors and a Weather Station Transmuter, Model 610028, manufactured by Meteorology Research Incorporated.

The magnetic tape used was Ampex 787 and was used for all data recordings. This tape is one inch wide, one mil thick, 4,600 feet long, and is wound on 10-1/2 inch, non-tapered, precision reels. At 3-3/4 ips, one reel of tape is capable of recording 4.10 hours of data.

4.3 Analysis Instrumentation

Preliminary analyses were accomplished at the site using a Brush Model 260 Strip Chart Recorder. This recorder was used to monitor the analog data being recorded on magnetic tape to provide an "immediate look" capability at this data. This could not be used for any critical analysis because of the mechanical limitations of the recorder to respond to input signals above 40 Hz. Also used for preliminary analysis was a Tektronix Storage Oscilloscope, Model 549, equipped with a model 1A4 plug-in amplifier.

The final spectral analysis of analog data was performed using a Federal Scientific real time Ubiquitous Spectrum Analyzer, Model UA-14A which performs analysis with 400 line resolution. The analyzer performs storage and speed up of the input signal to enable rapid spectrum analysis by step-heterodyning techniques. The signal in storage is both Fourier-analyzed to provide a spectrum presentation and, at the same time presented in the time domain for direct comparison on a convenient time base.

The Long Waveform Analysis System was also used to obtain a hard copy library of targets in the time and frequency domain. It is an interactive software system designed to digitize and display analog data. It is implemented on a PDP 11/45 computer with an analog to digital converter, tape units, time code reader, disk,and Tektronix 4002A display with hard copy. Other instrumentation used was a Tektronix Storage Oscilloscope, Model 7514, and a Telex/Midwestern direct record oscillograph, Model 1210.

5.0 Experimental Procedure

5.1 Calibration

Standard calibration procedures were used to determine the frequency response of the WIT preamplifier, audio amplifier, and the broadband amplifier. The preamplifier frequency response as shown in Figure 5-1 is .017 Hz to 10 KHz. The audio amplifier response as shown in Figure 5-2 is 66 Hz to 68 KHz. The broadband amplifier response as shown in Figure 5-3 is .043 Hz to 54 KHz. Voltage values recorded for the above calibrations are listed in Tables III, IV, and V respectively.

The Honeywell magnetic tape recorder was calibrated according to instructions in the Honeywell Maintenance Manual. All channels were recorded in the FM mode, intermediate band. The tape recorder speed was 3-3/4 ips; the bandwidth was 1,250 Hz with a center frequency of 6.75 KHz.

The selection of FM recording as the mode for data collection was based on the low frequency response of the transducer as well as the fact that targets of interest generate a substantial amount of low frequency (below 30 Hz) information down to and including DC. Direct recording, on the other hand, has a low frequency cut-off at approximately 100 Hz. However, the use of FM recording is not without some drawbacks. Intermediate band was used during

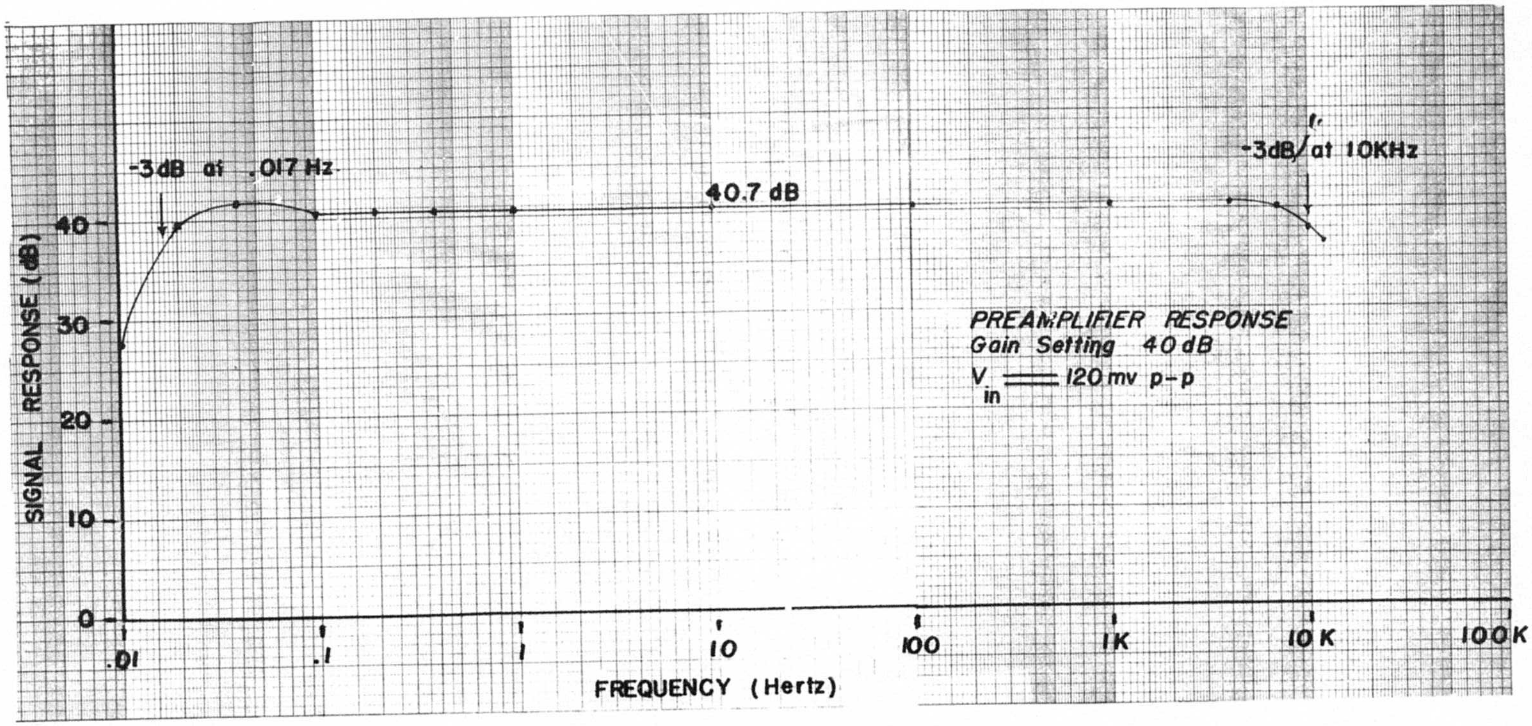

FIGURE 5-1. Preamplifier Response Curve

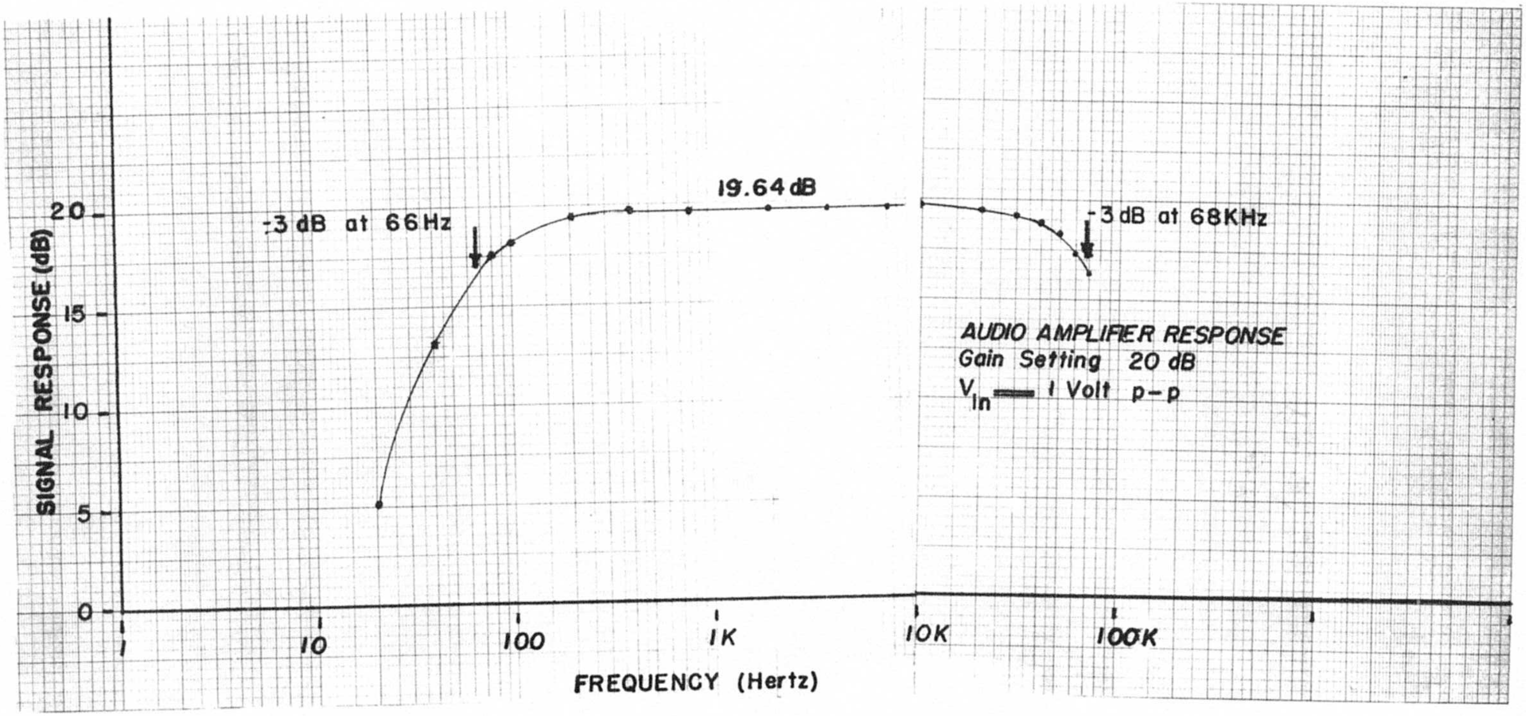

FIGURE 5-2. Audio Amplifier Response Curve

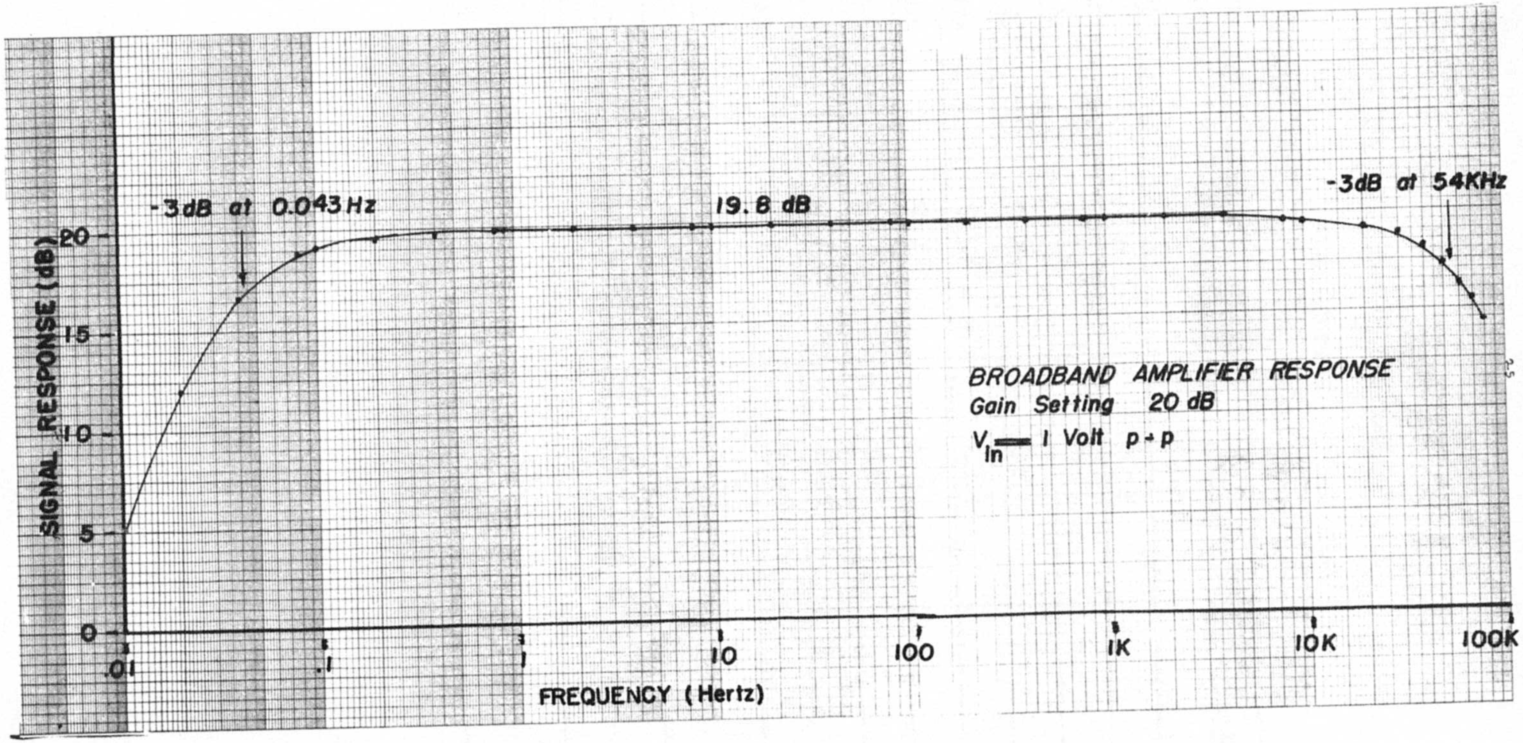

FIGURE 5-3. Broadband Amplifier Response Curve

TABLE III

PREAMPLIFIER RESPONSE DATA

FREQUENCY (Hz)	INPUT (mV)	OUTPUT (V)	GAIN (dB)
0.01	120	3.0	27.9
0.02	120	11.6	39.7
0.04	120	15.0	41.9
0.1	120	12.9	40.6
0.2	120	13.2	40.8
0.4	120	13.2	40.8
1.0	120	13.2	40.8
10.0	120	13.0	40.7
100.0	120	12.9	40.6
1000.0	120	12.8	40.6
4000.0	120	13.1	40.7
7000.0	120	12.6	40.4
10000.0	120	9.3	37.8
12000.0	120	8.4	36.9

TABLE IV

AUDIO AMPLIFIER RESPONSE DATA

FREQUENCY (H_Z)	INPUT (V)	OUTPUT (V)	GAIN (dB)
20	1	1.8	5.1
40	1	4.5	13.1
80	1	7.6	17.6
100	1	8.2	18.3
200	1	9.4	19.5
400	1	9.6	19.6
800	1	9.6	19.6
1000	1	9.6	19.6
2000	1	9.6	19.6
4000	1	9.6	19.6
8000	1	9.6	19.6
10000	1	9.6	19.6
20000	1	9.5	19.5
25000	1	9.4	19.4
30000	1	9.2	19.3
35000	1	9.1	19.2
40000	1	8.8	18.9
45000	1	8.6	18.7
50000	1	8.4	18.5
55000	1	8.0	18.1
60000	1	7.4	17.4
65000	1	7.0	16.9
70000	1	6.6	16.4

TABLE V

BROADBAND AMPLIFIER RESPONSE DATA

FREQUENCY (Hz)	INPUT (V)	OUTPUT (V)	GAIN (dB)
0.01	1	1.8	5.1
0.02	1	4.0	12.0
0.04	1	6.8	16.6
0.08	1	8.8	18.9
0.1	1	9.0	19.1
0.2	1	9.6	19.6
0.4	1	9.6	19.6
0.8	1	9.8	19.8
1.0	1	9.8	19.8
2.0	1	9.8	19.8
4.0	1	9.8	19.8
8.0	1	9.8	19.8
10.0	1	9.8	19.8
20.0	1	9.8	19.8
40.0	1	9.8	19.8
80.0	1	9.8	19.8
100.0	1	9.8	19.8
200.0	1	9.8	19.8
400.0	1	9.8	19.8
800.0	1	9.8	19.8
1000.0	1	9.8	19.8
2000.0	1	9.8	19.8
4000.0	1	9.8	19.8
8000.0	1	9.6	19.6
10000.0	1	9.5	19.5
20000.0	1	9.2	19.3
30000.0	1	8.8	18.9
40000.0	1	8.2	18.3
50000.0	1	7.4	17.4
60000.0	1	6.6	16.4
70000.0	1	6.0	15.6
80000.0	1	5.3	14.5

these experiments because of the availability of both record/ reproduce circuit cards and filters for this band. Once this band was selected, the bandwidth of the recording system would be determined by selecting the tape speed. Ideally, we should have selected a tape speed of 30 inches per second (ips). This would allow us to record frequencies from DC to 10 KHz which closely matches the bandwidth of the transducer. However, this would result in the consumption of an inordinate amount of magnetic tape which would be undesirable from cost, analysis and tape storage standpoints.

A tape speed of 3-3/4 ips was chosen which resulted in a capability of recording frequencies from DC to 1,250 Hz. The reasons for this selection were as follows[4]:

a. The targets of interest (men and vehicles) have previously been shown to emit energy predominately in frequency bands below 500 Hz.

b. While aircraft generate some energy at higher frequencies, it is usually propagated as air-acoustic energy and detected by above-ground microphones. This energy does not propagate efficiently through a seismic propagation channel and, therefore, is of little concern to these experiments. Energy generated by aircraft at lower frequencies is easily detected by the WIT.

c. The major portion of the energy attributed to noise sources propagating through seismic channels falls below 500 Hz.

Based on the above, it was felt that the objectives of these experiments could be met by selecting the above bandwidth.

All test equipment used for calibrations, data collections, and data analysis was calibrated by the Precision Measuring Equipment Laboratory located at Griffiss AFB at regular prescribed intervals.

5.2 Sensitivity and Repeatability

A specially designed drop hammer was fabricated to simulate the amplitude of a human foot step in order to obtain a highly repeatable source. The drop hammer is a device that produces a well-defined input signal produced by a 14-pound falling weight impacting a 3/8 inch thick, 12 inch diameter, steel, base plate. When the weight impacts the base plate, an impulse signal is imparted to the ground. To insure a single impulse, 2 inches of sponge rubber and 3/4 inch plywood are used between the falling weight and steel base plate to prevent bouncing of the falling weight after impact.

The drop hammer is armed by lifting the falling weight to a desired height. The weight is then held at this height by a simple release mechanism which consists of a light weight chain permanently attached to a "S" hook and an eye bolt permanently attached to the falling weight. Figure 5-4

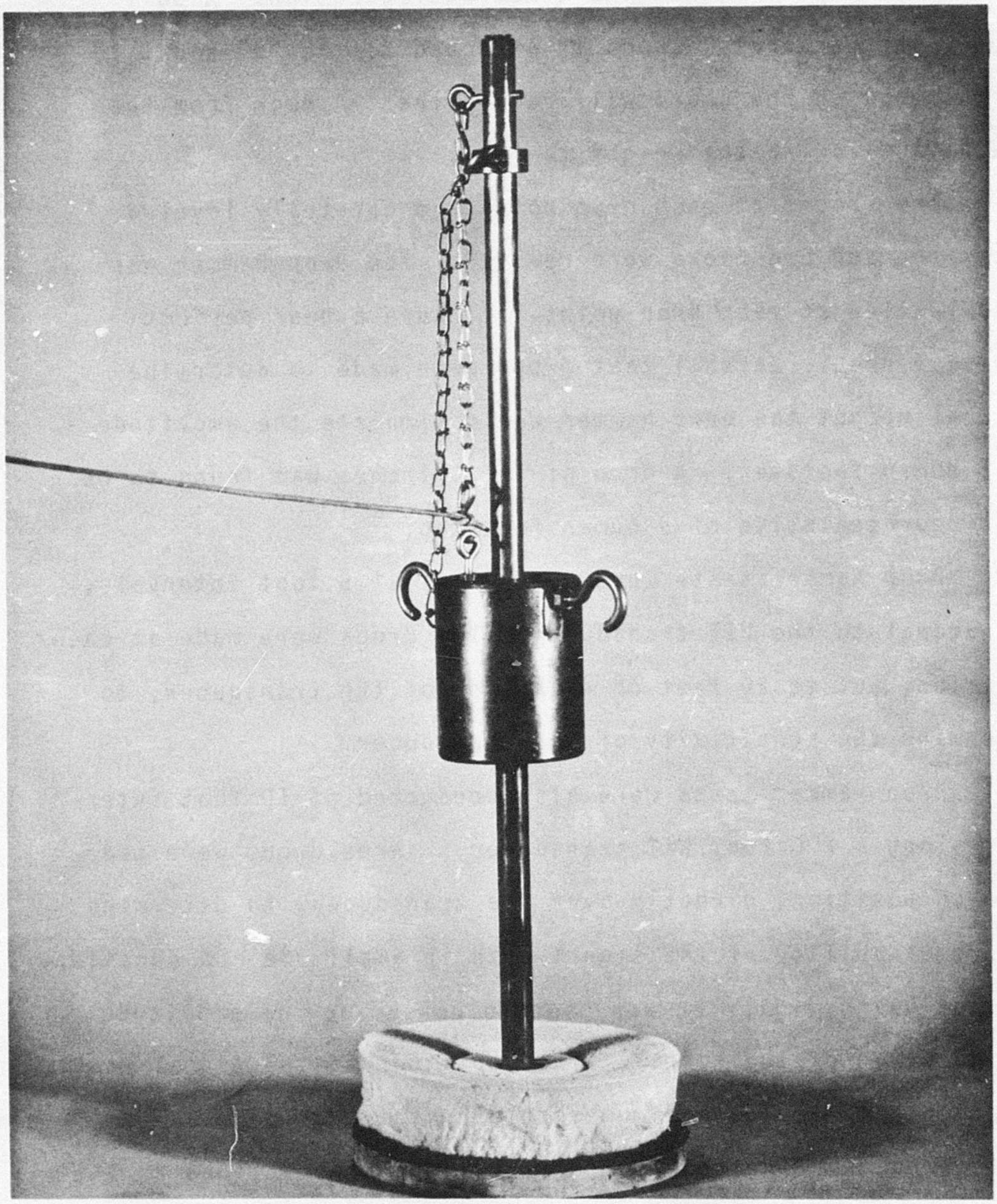

FIGURE 5-4. Drop Hammer

shows the drop hammer in the armed configuration. A 30 foot nylon parachute chord is attached to the "S" hook. A slight pull on the chord will remove the "S" hook from the eye bolt allowing the weight to fall.

The ground at each drop point was carefully leveled after the sod and rocks were removed. The drop hammer was also leveled at each drop point to insure a near perfect vertical drop. Several test drops were made to determine at what height the drop hammer would simulate the amplitude of a human footstep. A drop of 1-1/8 inches was found to be most representative of a human footstep.

Drop hammer tests were conducted, at 5 foot intervals, orthogonal to the WIT transducer. Two drops were made at each position, out to 20 feet on each side of the transducer, to determine the sensitivity of the transducer.

Drop hammer tests were also conducted at 10 foot intervals along a 200 foot WIT transducer. Three drops were made at each position, directly over the transducer, to determine the repeatability of the signal both in amplitude and duration. The following criterion was used to determine the amplitude and duration of the signal. The amplitude of the signal was determined to be the maximum single cycle, peak to peak voltage value. The duration of the signal was defined as the time from the onset of the impulse to the point where the signal decayed to 15% of the maximum amplitude.

5.3 Frequency Response

The first series of tests performed by Westinghouse was to determine the size of the inner conductor having the best overall response as a function of frequency. This was accomplished in the laboratory using the instrumentation shown in Figure 5-5. Here, a vibrator is driven by a power frequency generator to a desired frequency and amplitude as monitored by the oscilloscope connected to the pickup coil. The WIT output is connected to a high input impedance amplifier, the output of which is connected to an oscilloscope for monitoring. As the frequency is varied throughout the range of interest, the amplitude is adjusted to compensate for mechanical resonances and other effects.

The above vibrator test covered a frequency range of 0.1 Hz to 1,000 Hz. In addition to this test, a simple test was conducted in our laboratory to determine if the WIT transducer would respond to frequencies higher than 1,000 Hz. A sweep frequency generator was connected to an audio amplifier and speaker. The WIT transducer was placed in close proximity to the speaker with the output connected to a spectrum analyzer and hard copy unit.

In addition to the above laboratory tests a library of targets was recorded on analog tape. These tapes were then analyzed in the Data Analysis Facility using fast fourier transforms and a library of hard copy spectrum presentations was made.

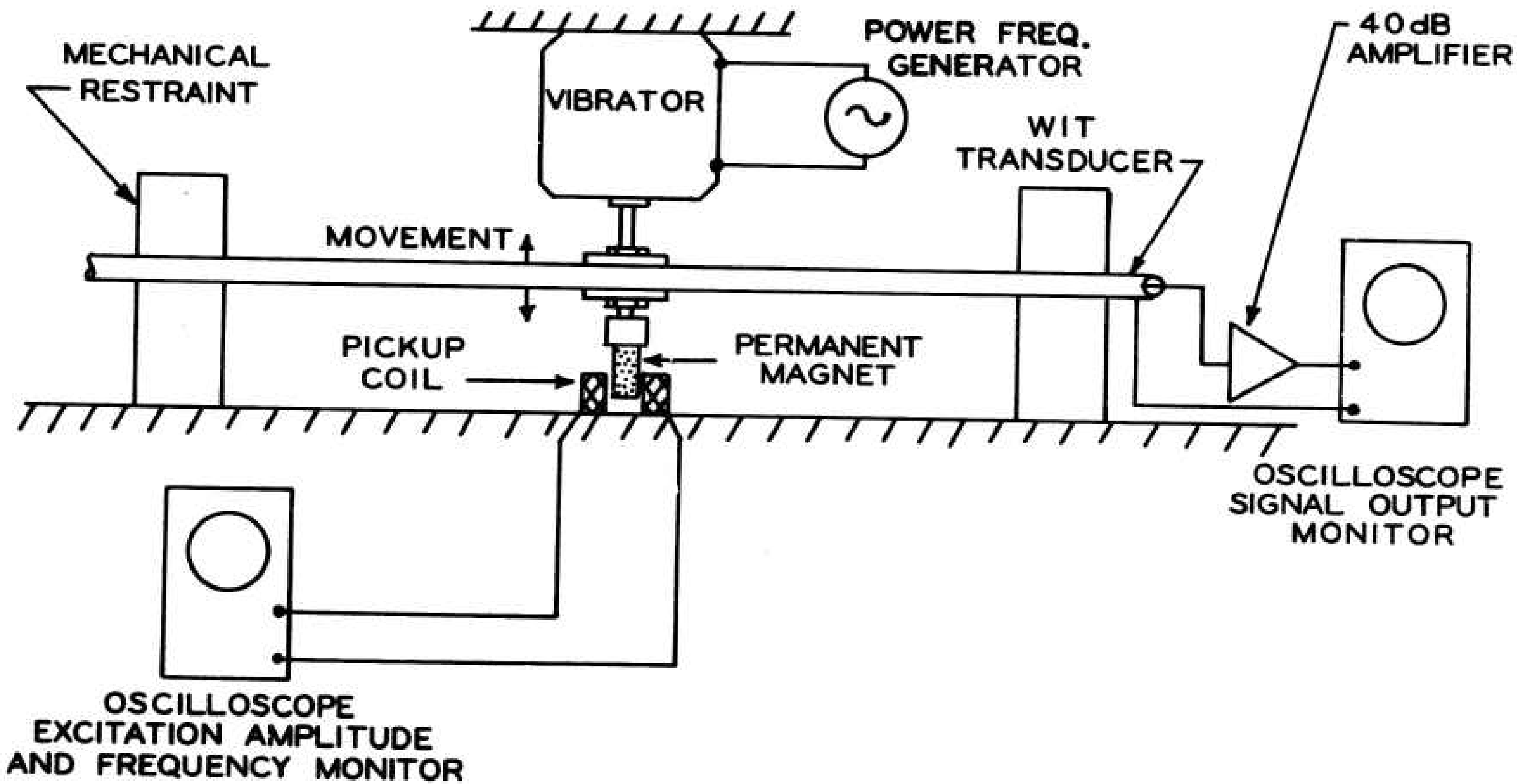

FIGURE 5-5. Instrumentation for Measuring Frequency Response

5.4 Stability

During a variety of ground and environmental conditions, analog recordings were made of human intruders and other targets of opportunity. During this time, wind speed and direction, frost lines, and snow depths were recorded.

6.0 Experimental Results

6.1 Repeatability

Drop hammer tests were conducted, along the WIT transducer, to determine if the transducer would produce a repeatable signal for the same target or stimulation. A repeatable signal would indicate that the 26 gauge, teflon coated, inner conductor returns to its original position in the copper tube after being displaced. It was important to determine if the wire returned to its original position in order to consider the future use of classification logic with the WIT transducer. Test results tabulated in Tables VI and VII indicate a high degree of repeatability for a single station and a large variance in the repeatability at successive stations for both WIT-1 and WIT-2. This large variance at successive stations is also shown in Figures 6-1 and 6-2. The inconsistency of the electret potential on the teflon insulation, as received from the manufacturer, is one reason for this variance. A graph of the electret potential as a function of wire length was extracted from a Westinghouse report[3] and is shown in Figure 6-3.

6.2 Sensitivity

To determine how the WIT output signal attenuates as a function of distance from the transducer, orthogonal profiles were made using the drop hammer as a stimulus. From the data

TABLE VI
REPEATABILITY DATA-WIT #1, AUDIO CHANNEL

Line Position	Volts P-P Single Cycle					Signal Duration (Millimeters)			
	Drop #1	Drop #2	Drop #3	Avg	15% Avg	Drop #1	Drop #2	Drop #3	Avg
0	1.6	1.6		1.6	.24	189	194		192
10	6.0	5.6		5.8	.87	167	166		167
20	6.7	8.0		7.4	1.11	106	105		106
30	5.6	6.0	6.0 (5.6)	6.0	.9	137	143	142 (136)	140
40	7.6	7.8	8.8	7.7	1.16	114	114	113	114
50	4.9	8.0	4.7 (6.0)	4.8	.72	151	167	138 (161)	160
60	3.3	3.0		3.2	.48	132	131		132
70	6.0	6.8		6.4	.96	122	117		120
80	5.4	4.4	4.6	4.5	.68	151	155	155	155
90	3.6	3.6		3.6	.54	201	181	191	191
100	3.4	3.2		3.3	.5	191	214		203
110	4.6	5.2		4.9	.74	137	132		135
120	5.2	4.6		4.9	.74	129	129		129
130	4.1	4.8		4.4	.66	125	124		125
140	3.9	3.8	4.2	4.0	.6	142	132	173	137
150	1.2	1.2	1.5	1.2	.18	111	102		107
160	2.6	2.5		2.6	.39	143	141	102	142
170	2.0	1.3	1.2	1.3	.2	146	145	143	145
180	2.6	2.4		2.5	.38	168	168		168
190	4.0	3.6		3.8	.57	148	150		149
200	4.4	4.2		4.3	.64	122	129		126
210	1.6	1.6		1.6	.24	183	177		180
220	2.4	2.8	2.1 (2.6)	2.4	.36	147	147		147
230	1.7	1.9		1.8	.27	152	165		159
240	2.1	2.1		2.1	.32	113	113		113
250	1.5	1.1	1.2	1.2	.18	114	118	117	116
260	1.9	1.5	2.0 (1.5)	1.5	.22	126	130	130	130
270	2.2	2.5		2.4	.36	173	170		172
280	1.6	1.7		1.6	.24	189	189		189
290	1.3	1.5		1.4	.21	152	148		150
300	.9	.8	.6	.8	.12	87	87	89	88

TABLE VII
REPEATABILITY DATA-WIT #2, AUDIO CHANNEL

	Volts P-P Single Cycle					Signal Duration (Millimeters)			
Line Position	Drop #1	Drop #2	Drop #3	Avg	15% Avg	Drop #1	Drop #2	Drop #3	Avg
0	24.0	19.2	23.2	22.1	3.32	99	99	99	99
10	6.6	5.8	5.6	5.7	.86	96	97	96	96
20	6.4	5.6	5.6	5.6	.84	199	201	201	201
30	7.8	7.6	7.6	7.6	1.14	120	120	120	120
40	9.6	8.8	9.2	9.2	1.38	111	111	111	111
50	4.1	4.3	4.4	4.3	.64	154	153	155	154
60	4.3	4.7	4.2	4.3	.64	177	179	178	178
70	3.8	3.7	3.6	3.7	.56	223	220	211	218
80	13.2	14.4	13.2	13.2	1.98	121	126	121	121
90	10.8	8.4	8.4	8.4	1.26	145	143	143	143
100	4.0	4.0	3.8	4.0	.60	205	205	206	205
110	11.2	10.8	10.4	10.8	1.62	194	192	190	192
120	8.4	8.8	8.8	8.8	1.32	161	161	161	161
130	6.0	5.4	5.0	5.5	.82	159	158	158	158
140	3.3	3.0	3.6	3.3	.50	134	134	134	134
150	4.6	4.0	3.2	3.9	.58	127	127	127	127
160	2.4	2.2	2.2	2.2	.33	182	181	181	181
170	5.4	4.2	4.0	4.1	.62	139	139	138	139
180	3.8	4.2	4.6	4.2	.63	145	147	136	143
190	3.6	3.2	3.0	3.3	.50	107	107	113	107
200	4.3	4.1	4.2	4.2	.63	117	117	116	117
210	2.7	2.7	2.3	2.7	.40	162	159	163	161
220	2.8	3.4	2.8	2.8	.42	145	142	142	142
230	4.4	4.0	4.4	4.4	.66	130	131	128	130
240	3.8	4.0	3.8	3.8	.57	143	142	142	142
250	5.6	6.4	6.2	6.3	.94	81	81	81	81
260	3.0	3.3	3.2	3.2	.48	137	137	136	137
270	2.5	3.0	2.6	2.6	.39	121	120	122	121
280	1.6	1.6	1.6	1.6	.24	150	152	151	151
290	3.4	2.7	2.8	2.8	.42	93	99	96	96
300	1.4	1.8	2.1	1.8	.27	96	104	99	100

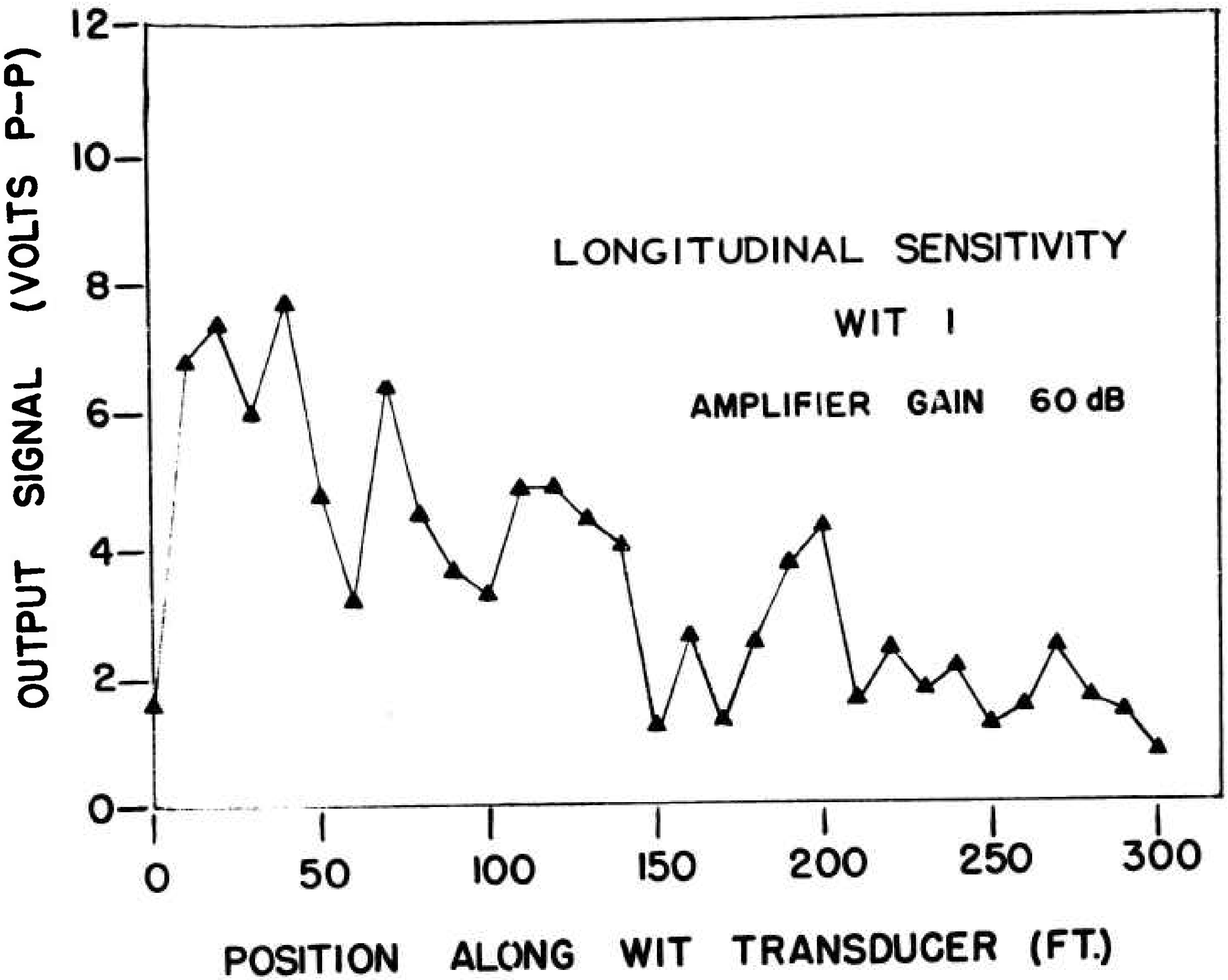

FIGURE 6-1. Longitudinal Sensitivity of WIT #1

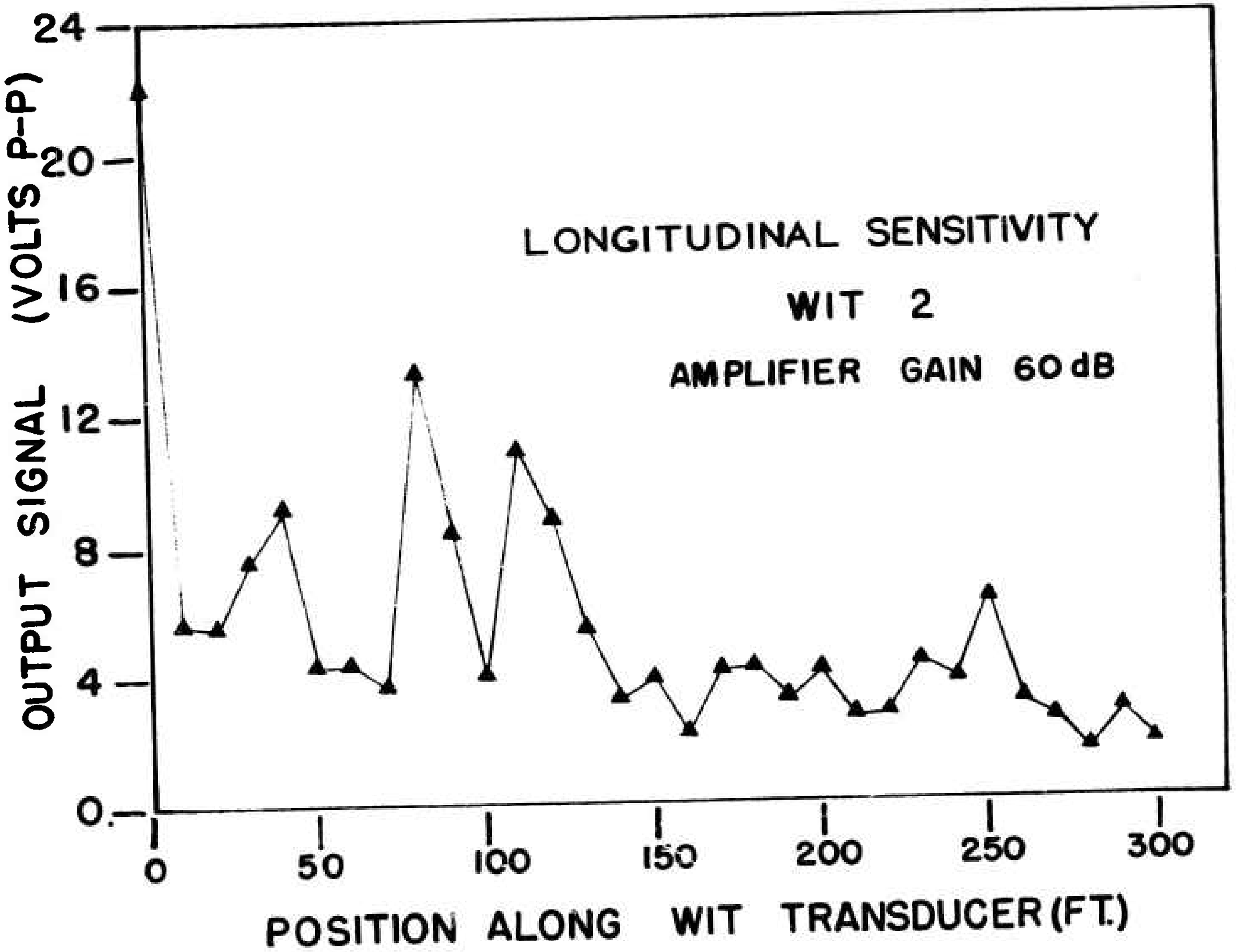

FIGURE 6-2. Longitudinal Sensitivity of WIT #2

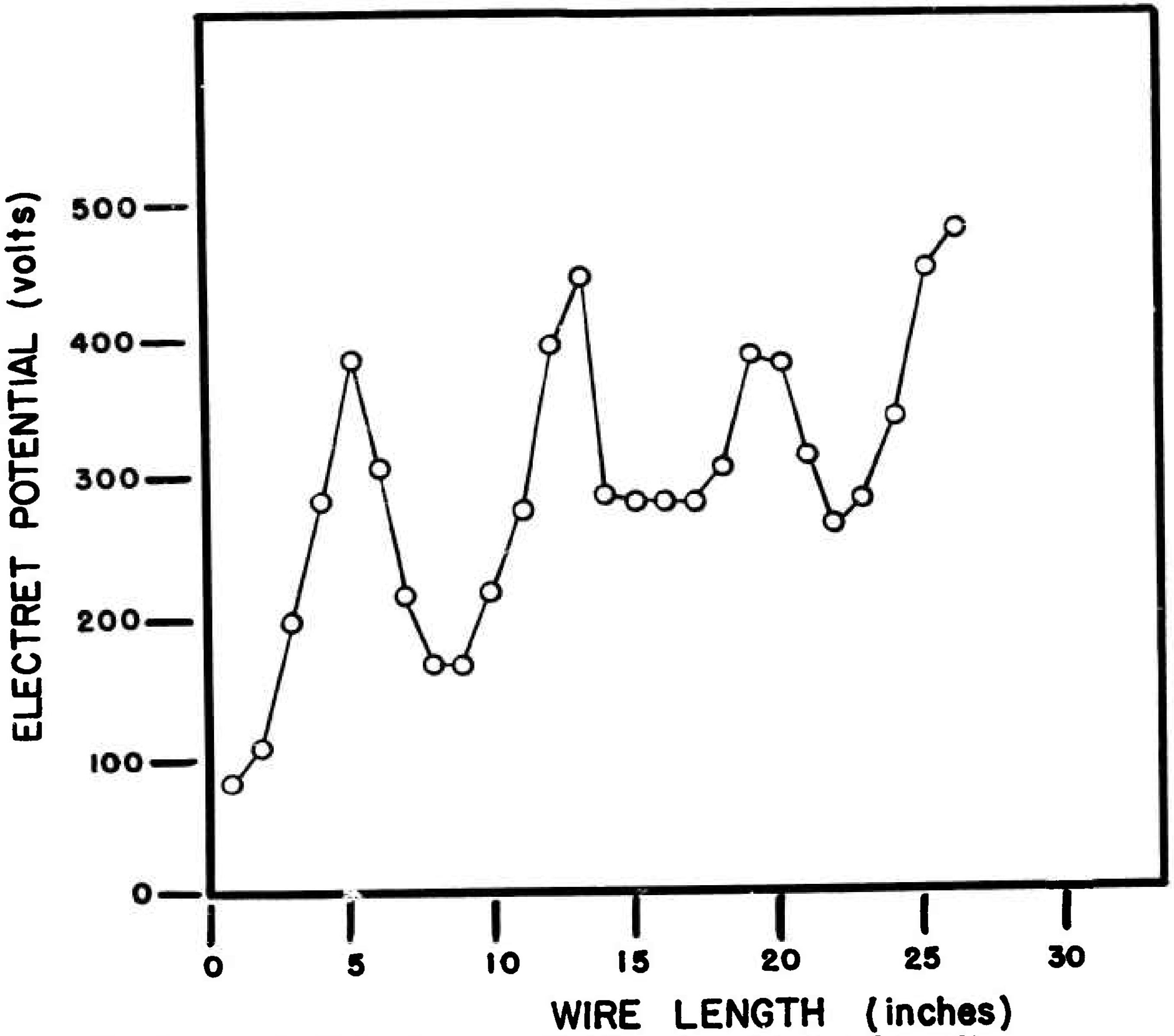

FIGURE 6-3. Electret Potential as a Function of Length for Teflon Insulated Wire as Received from the Manufacturer

in Tables VIII and IX, typical sensitivity profiles for WIT 1 and 2 are shown in Figures 6-4 and 6-5 respectively. The variations in the profile curves are due to the differences of the ground conditions along the transducer length and inconsistency of the electret potential on the teflon insulation, as described in paragraph 6.1

The drop hammer was originally set such that the amplitude of the signal produced approximates that of a footstep when the intruder is walking normally at a rate of 3 feet per second. Based on this arrangement, the range of detection for a human can be considered to be contained within a corridor that is 20 feet on each side of the transducer. As an intruder increases his speed the corridor will widen due to a greater impact of his foot on the ground. As the intruder's speed decreases, the corridor will also decrease but there is no speed or aspect of approach that will allow an intruder to cross the transducer, under normal operating conditions, without being detected. Detection in this case means visual and/or audible detection by monitoring a stripchart recorder or listening to a speaker.

6.3 Frequency Response

The vibrator tests performed by Westinghouse, as described in paragraph 5.3, show that a #26 gauge teflon wire had the best overall response, especially at low frequency excitation. A graph of this response from .1 Hz to 1,000 Hz is shown in

TABLE VIII

WIT #1 ORTHOGONAL PROFILES

Line Position	Volts P-P Single Cycle Drop #1	Drop #2	Avg
10 - 20W	.675	.75	.7125
10 - 15W	1.10	1.20	1.15
10 - 10W	.60	.8	.7
10 - 5W	1.50	1.1	1.3
10 - 0	4.20	--	4.2
10 - 5E			
10 - 10E			
10 - 15E			
10 - 20E			
60 - 20W	.55	.425	.4875
60 - 15W	.80	.925	.8625
60 - 10W	1.8	1.8	1.8
60 - 5W	1.4	1.5	1.45
60 - 0	3.1	3.2	3.15
60 - 5E	2.0	2.2	2.1
60 - 10E	1.75	1.8	1.78
60 - 15E	.575	.5	.538
60 - 20E	.65	.5	.575
120 - 20W	.45	.50	.475
120 - 15W	.575	.575	.575
120 - 10W	1.0	1.05	1.025
120 - 5W	2.1	2.0	2.05
120 - 0	3.1	3.5	3.3
120 - 5E	1.225	1.10	1.162
120 - 10E	1.10	1.05	1.075
120 - 15E	.55	.625	.588
120 - 20E	.50	.525	.512
180 - 20W	.325	.30	.312
180 - 15W	.40	.475	.438
180 - 10W	.375	.35	.362
180 - 5W	.875	.625	.75
180 - 0	5.20	4.60	4.9
180 - 5E	2.25	2.3	2.28
180 - 10E	1.1	1.2	1.15
180 - 15E	.85	.70	.775
180 - 20E	.55	.50	.525
240 - 20W	.35	.40	.375
240 - 15W	.30	.25	.275
240 - 10W	.30	.25	.275
240 - 5W	.425	.40	.412
240 - 0	6.50	6.0	6.25
240 - 5E	1.05	1.1	1.08
240 - 10E	.6	.588	.594
240 - 15E	.538	.338	.438
240 - 20E	.325	.275	.3

TABLE IX

WIT #2 ORTHOGONAL PROFILES

Line Position	Volts P-P Single Cycle			
	Drop #1	Drop #2	Drop #3	Avg
10 - 20W	.8	.5	.5	.65
10 - 15W	.675	.8		.738
10 - 10W	.95	1.025		.988
10 - 5W	1.9	1.45	2.45 1.65 2.25	1.935
10 - 0	6.4	7.2		6.8
10 - 5E	1.45	1.45		1.45
10 - 10E	.9	1.0		.95
10 - 15E	.575	.55		.5625
10 - 20E	.325	.35		.3375
60 - 20W	.8	.788		.794
60 - 15W	.9	.8		.85
60 - 10W	2.0	1.53		1.765
60 - 5W	2.7	2.3		2.5
60 - 0	6.2	5.2		5.7
60 - 5E	2.3	1.75		2.025
60 - 10E	1.2	1.1		1.15
60 - 15E	.55	.6		.575
60 - 20E	.675	.75		.7125
120 - 20W	.75	.762		.756
120 - 15W	.9	1.15		1.025
120 - 10W	2.0	1.85		1.925
120 - 5W	5.8	6.6		6.2
120 - 0	9.6	10.4		10.0
120 - 5E	9.9	8.4		9.15
120 - 10E	2.15	1.6	1.6	1.6
120 - 15E	1.78	1.8		1.79
120 - 20E	1.0	1.075		1.038
190 - 20W	.65	.55	.5	.566
190 - 15W	.95	.95		.95
190 - 10W	1.05	1.1		1.075
190 - 5W	2.1	1.85		1.975
190 - 0	4.4	5.4	5.0	4.93
190 - 5E	1.45	1.4		1.425
190 - 10E	1.05	1.05		1.05
190 - 15E	.55	.65		.6
190 - 20E	.5	.5		.5
240 - 20W	.25	.175		.2125
240 - 15W	.55	.575		.562
240 - 10W	.512	.412		.462
240 - 5W	.65	.8		.725
240 - 0	3.3	2.4		2.85
240 - 5E	1.05	1.32		1.185
240 - 10E	.575	.65		.612
240 - 15E	.338	.438		.383
240 - 20E	.3	.45	.412 .412 .425	.412

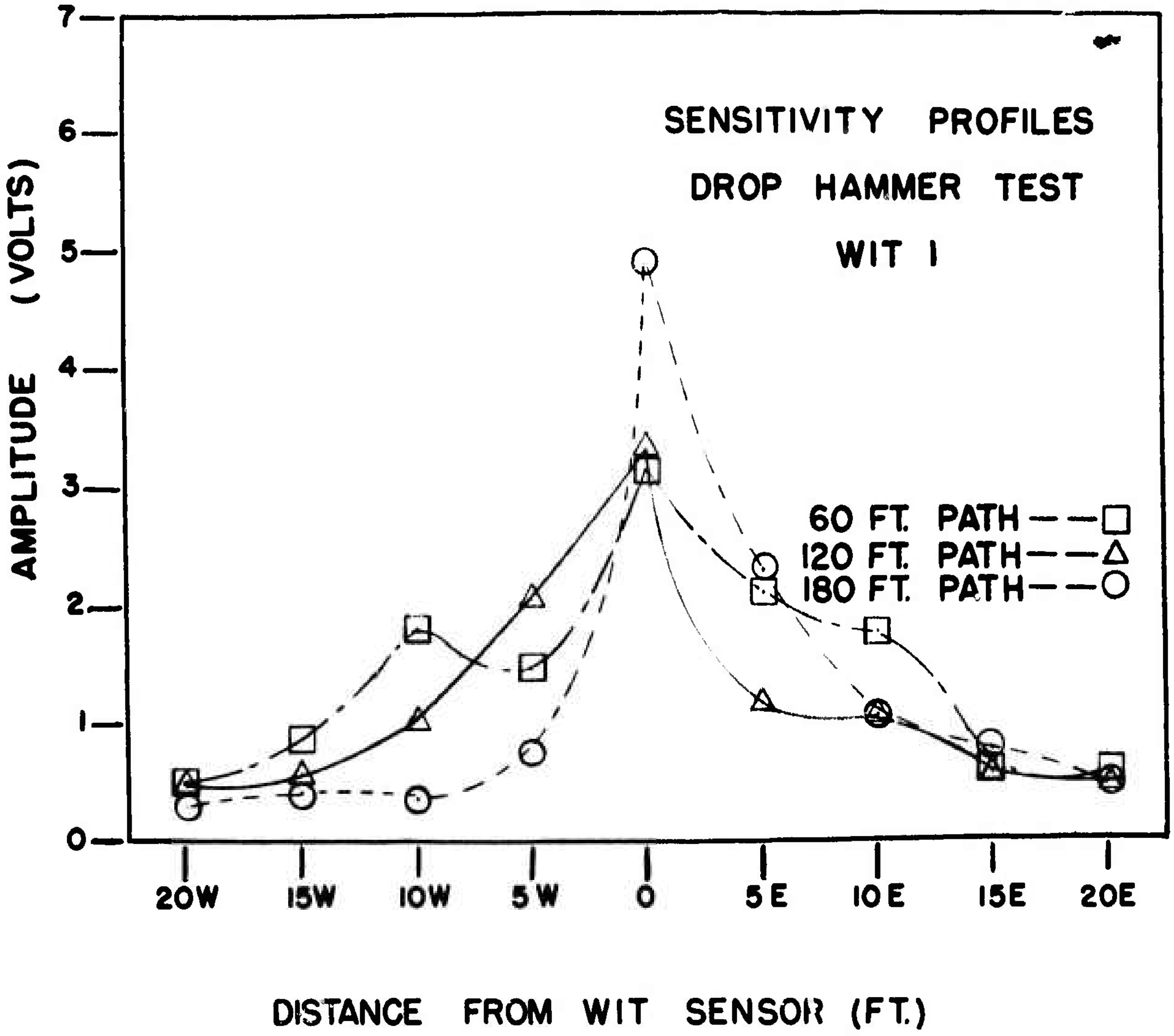

FIGURE 6-4. Sensitivity Profile, WIT #1

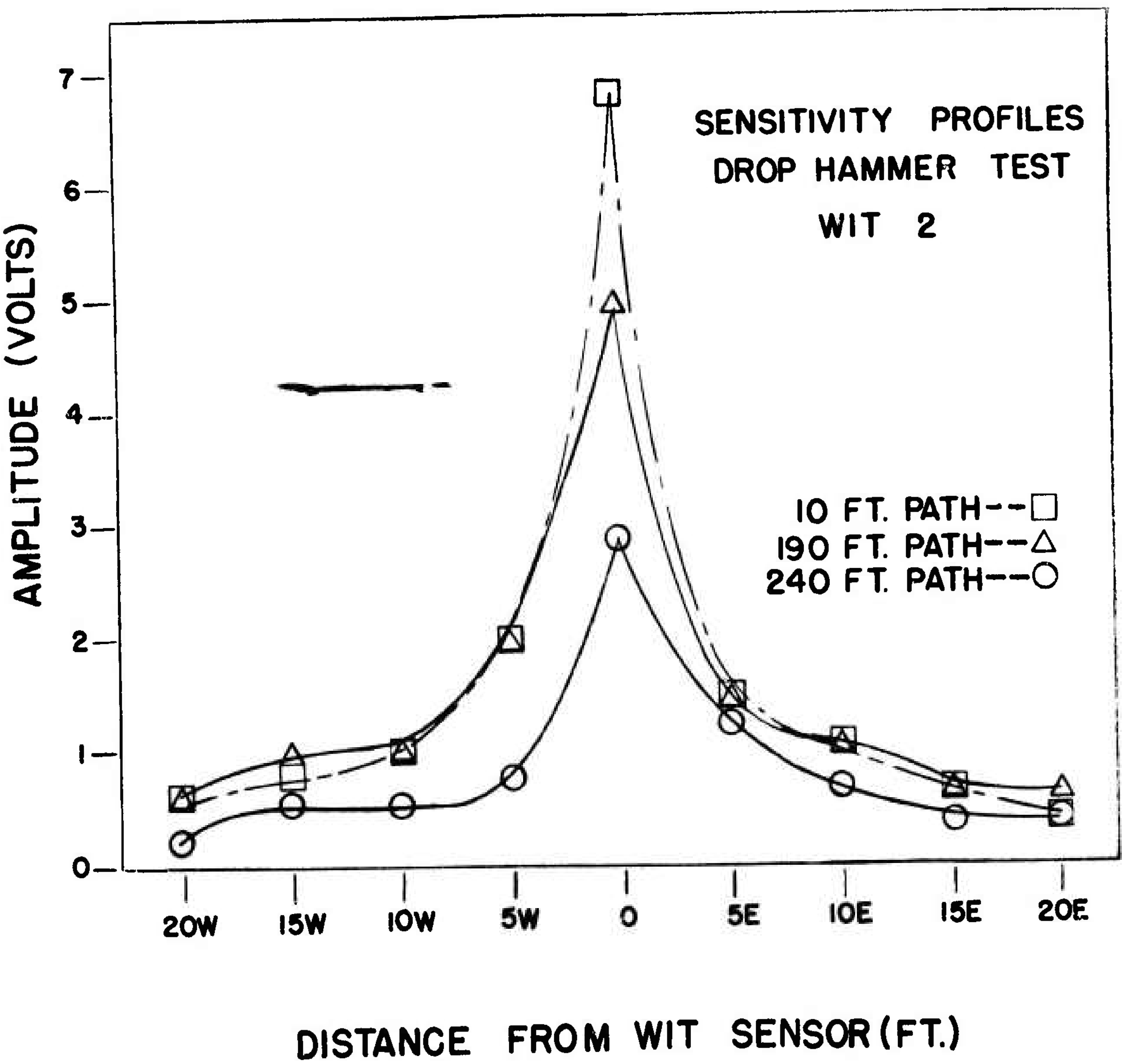

FIGURE 6-5. Sensitivity Profile, WIT #2

Figure 6-6. In the simple speaker experiment conducted in our laboratory, we swept the frequency from 1 KHz to 20 KHz. The output from the WIT is shown in Figure 6-7. No attempt was made to faithfully measure the amplitude of the WIT response since the seismic propagation channel greatly attenuates high frequency information limiting air-coupled seismic information to approximately 1 kilohertz.[4]

In addition to the above laboratory tests, a hard copy library was constructed from the analog data collected at Site 2D. Plots from this library, in the time and frequency domain, are shown in Figures 6-8 thru 6-35.

On all time domain plots, the sample rate (ESR) is given along with maximum and minimum voltage swing of the analog signal. The bandwidth (BW) is given at the top at each frequency domain plot. To determine the frequency increment, divide the bandwidth by 25 (total number of increments on the frequency scale).

6.3.1 Drop Hammer

Figure 6-8 shows the analog response due to the 14 lb drop hammer released from a height of 1-1/8", directly over the WIT transducer. Figure 6-9 shows the spectral content of the drop hammer signal. The Analog Signal from the Audio Channel was used for this presentation and is the reason for the absence of frequencies below 30 Hz.

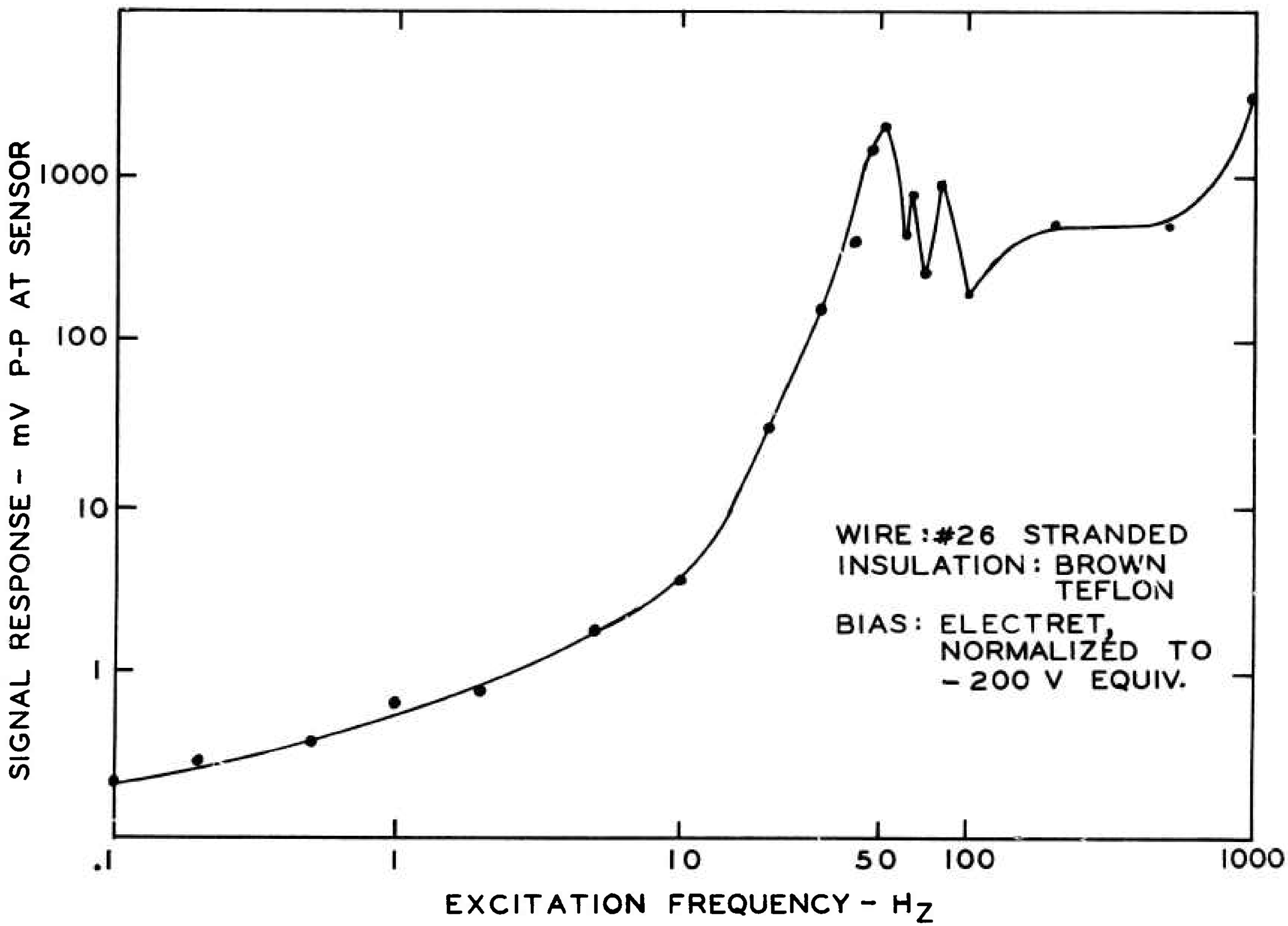

FIGURE 6-6. Frequency Response for 26-Gauge Wire

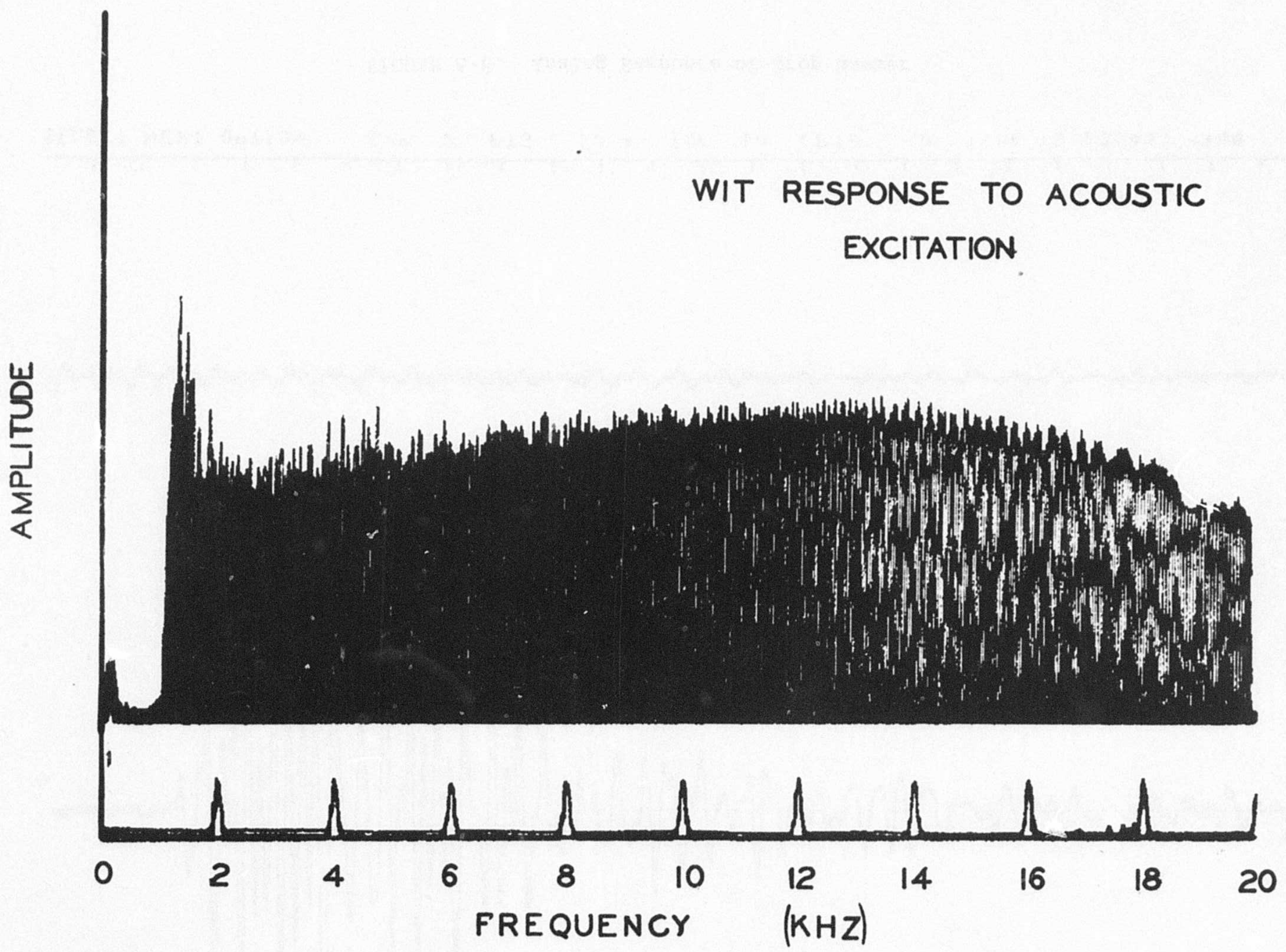

FIGURE 6-7. Sweep Frequency Response of WIT Transducer

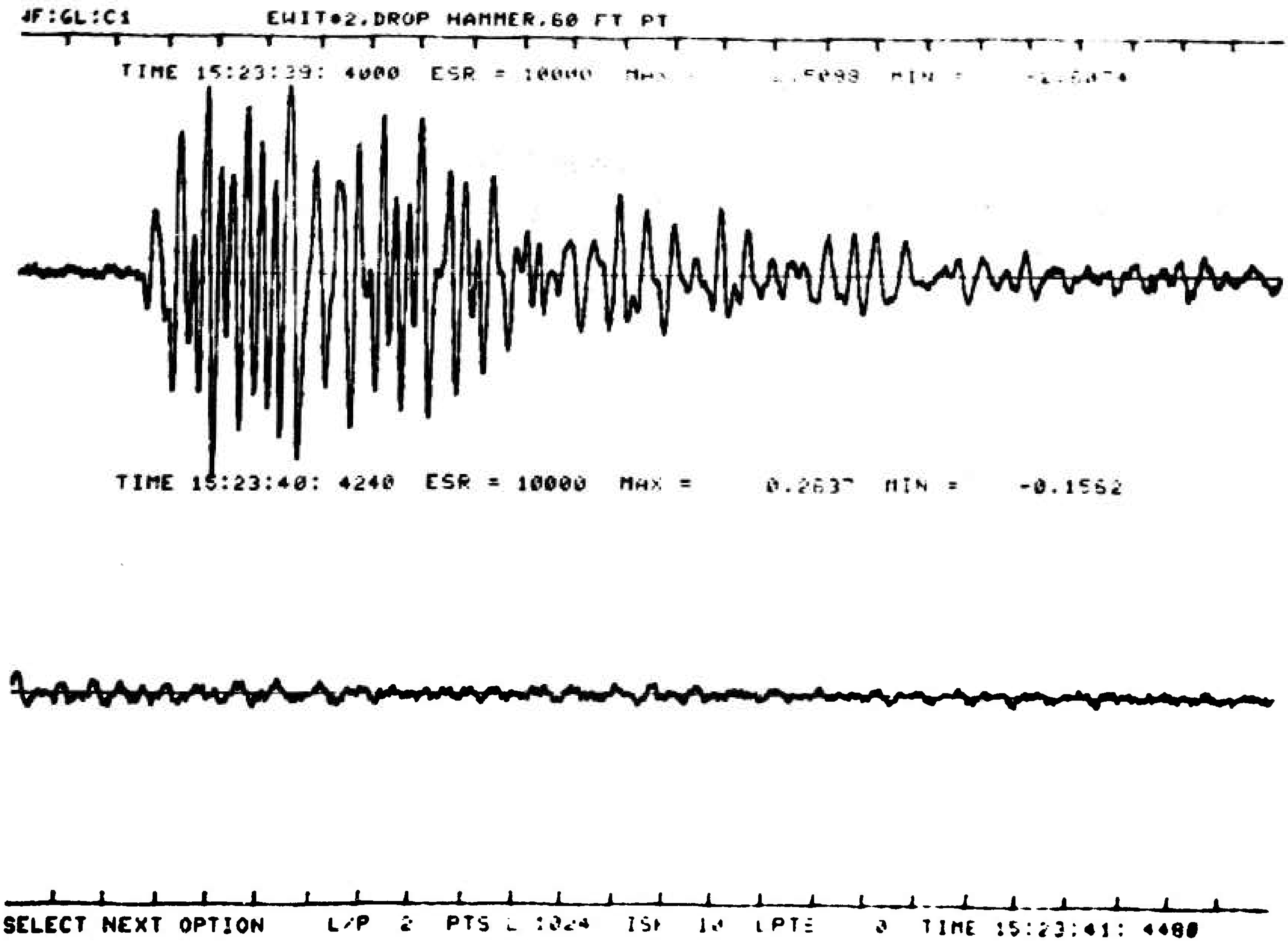

FIGURE 6-8. Analog Response of Drop Hammer

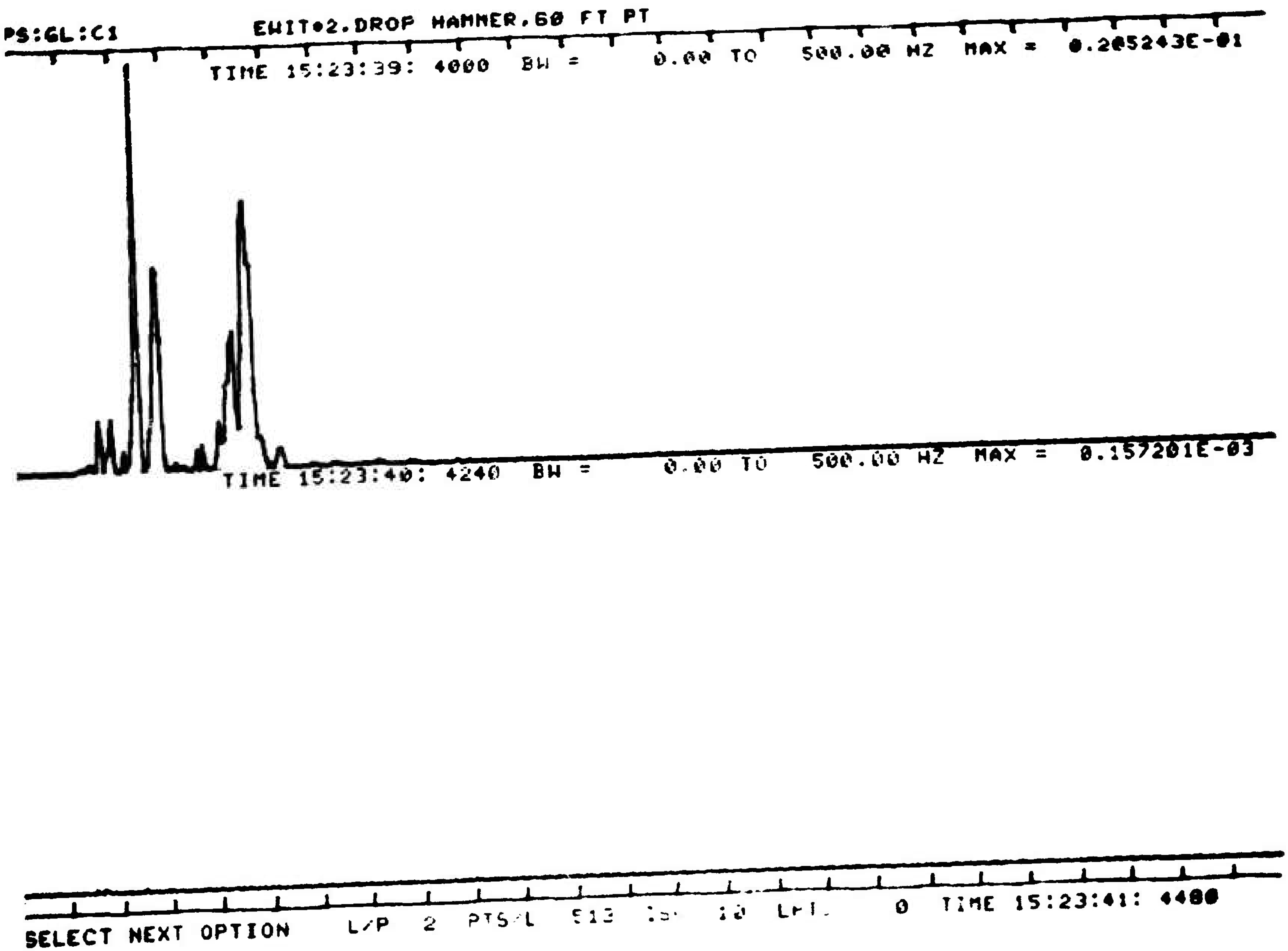

FIGURE 6-9. Power Spectrum of Drop Hammer

6.3.2 Human

A comparison between a human intruder crawling, walking, and running is shown in Figure 6-10 thru 6-15. The spectral presentations show as the intrusion type changes from a crawl, walk, and then to a run the spectrum changes from a low frequency content to a greater high frequency content.

6.3.3 Voice

An intruder speaking in close proximity to the WIT transducer can distinctly be heard on a speaker connected to the WIT electronics. Figure 6-16 shows the analog signal of a man counting in a strong speaking voice (not shouting). The man is standing in an upright position directly over the transducer. The discrete numbers can distinctly be seen in the spectral presentation shown in Figure 6-17. The main frequency content is approximately 600 Hz. The other frequencies of 60, 180 and 300 Hz shown in the presentation are due to noise generated in the computer's A to D converter.

6.3.4 Aircraft

Figures 6-18 thru 6-21 shown the WIT's response to piston and jet aircraft. A doppler shift is shown in the spectral presentation of the piston aircraft. The spectral presentation for the jet aircraft shows a higher energy content over most of the frequency spectrum.

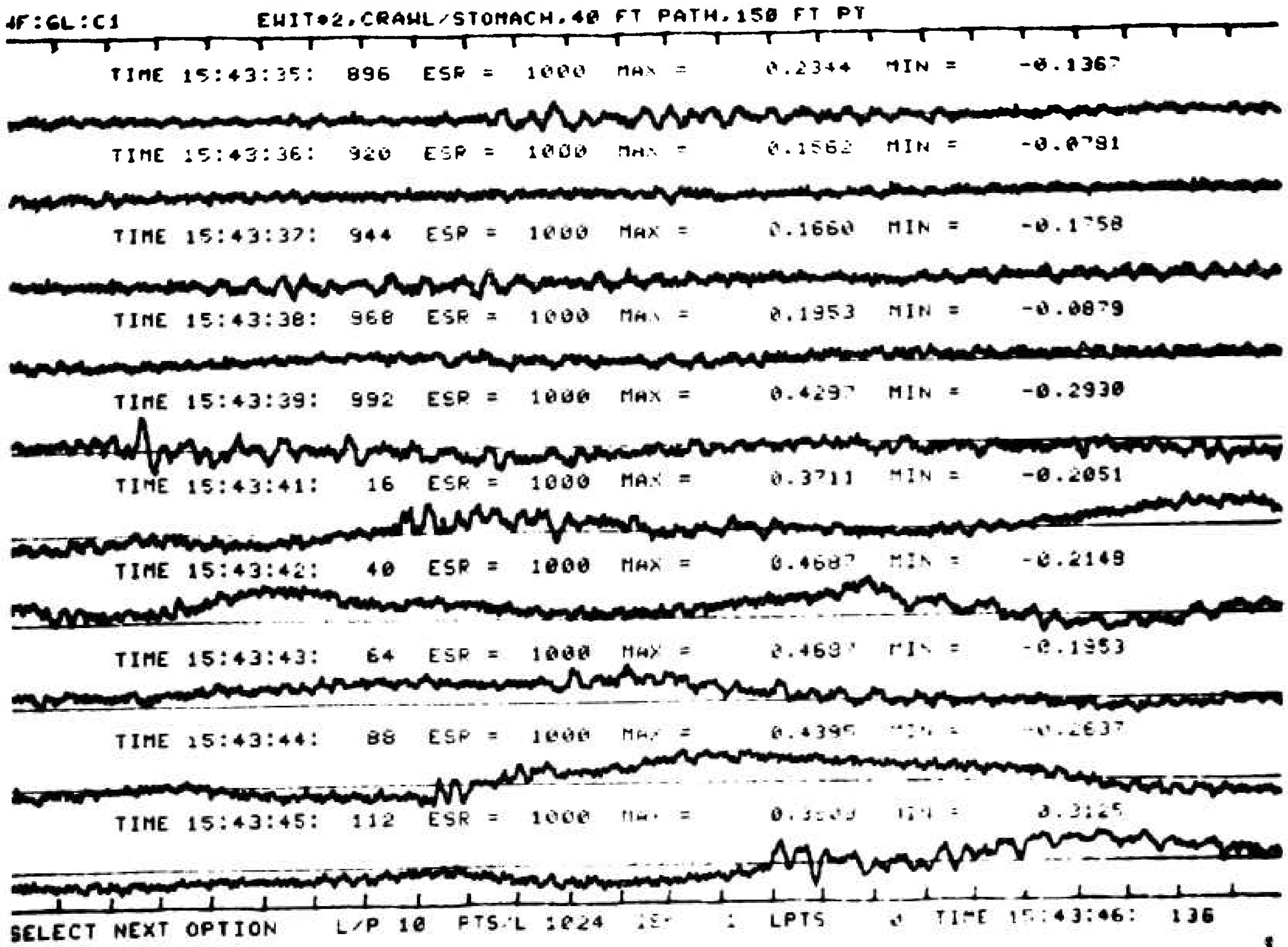

Figure 6-10. Analog Response of Human Crawling

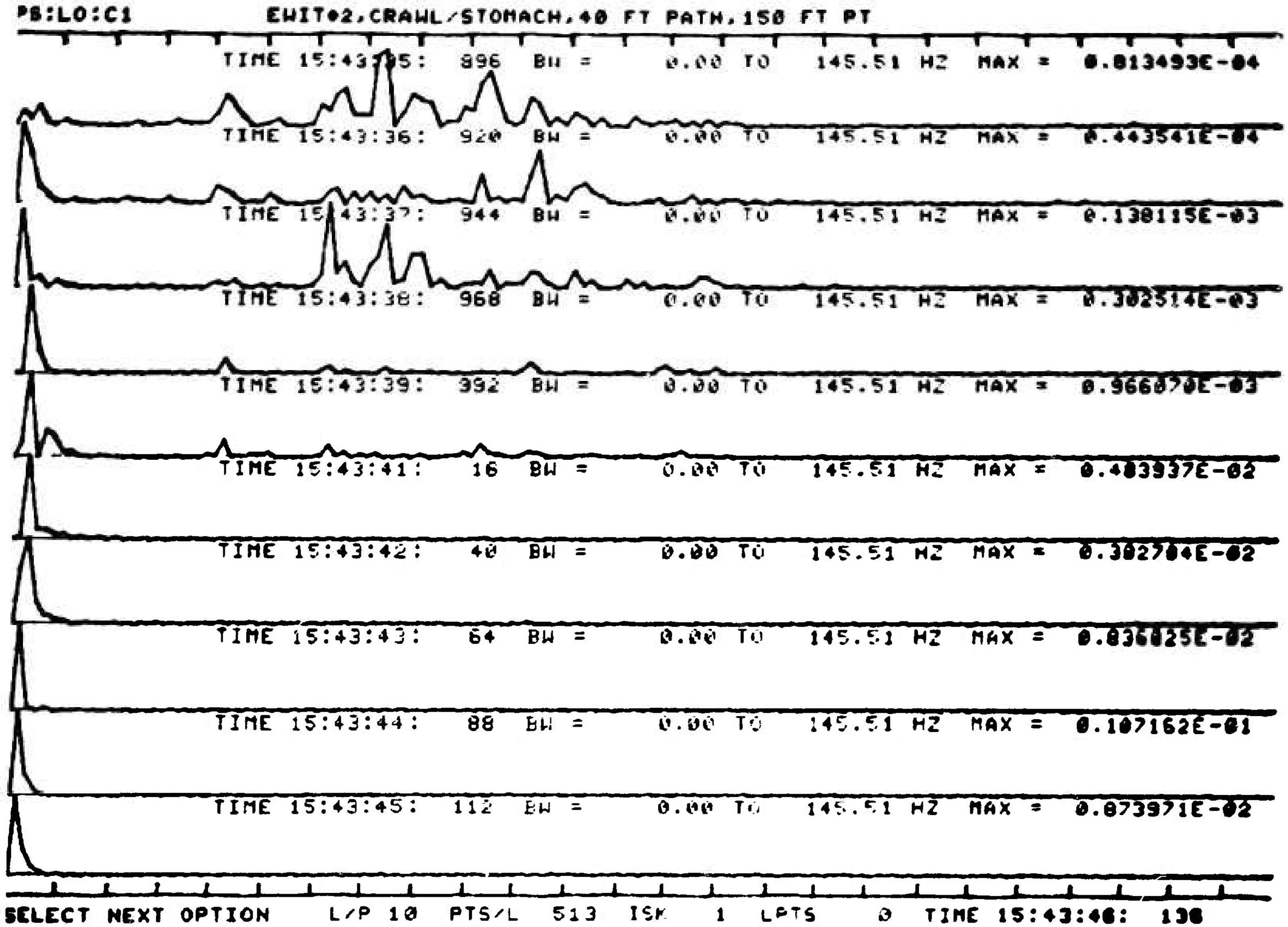

Figure 6-11. Power Spectrum of Human Crawling

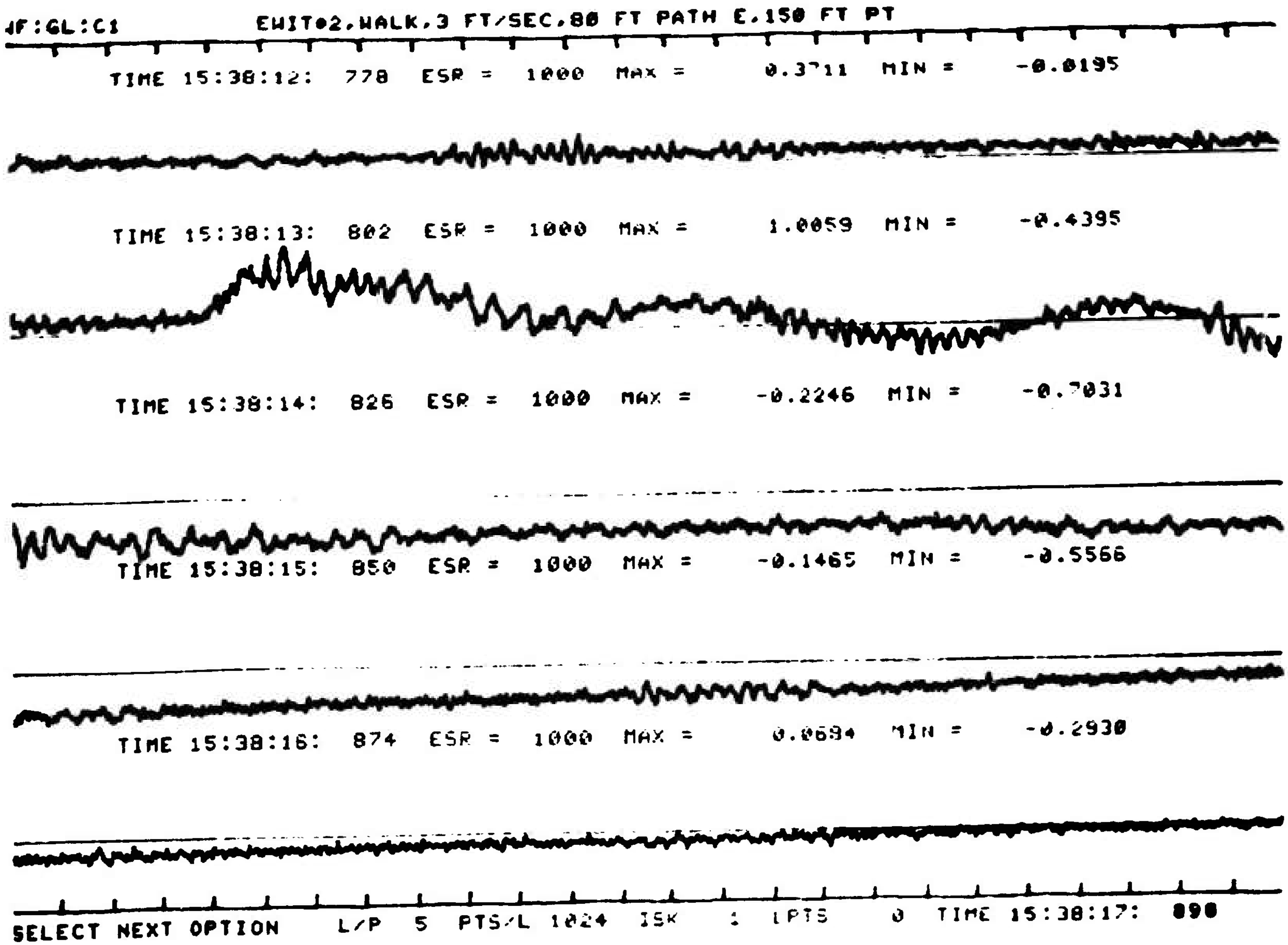

Figure 6-12. Analog Response of Human Walking

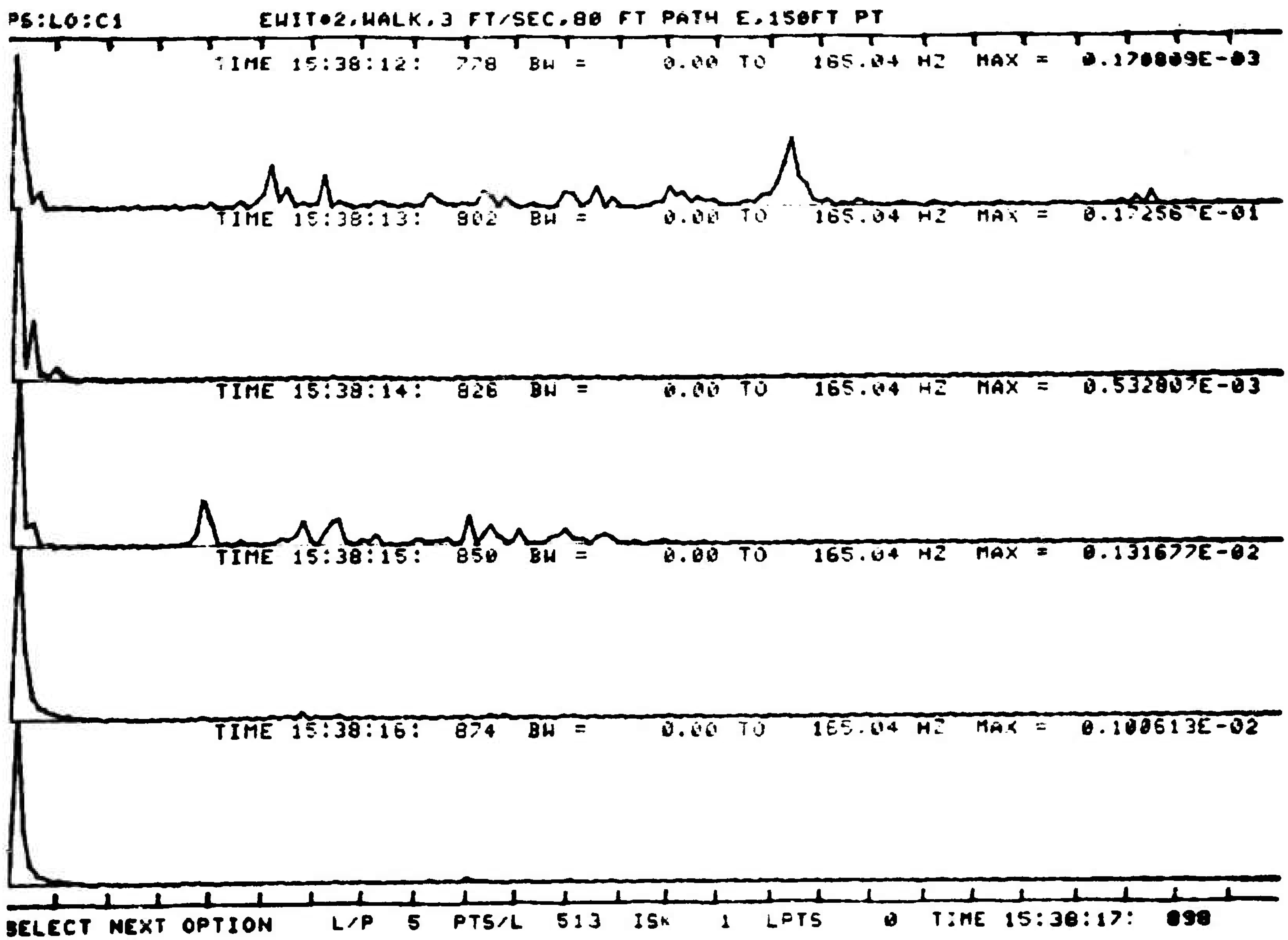

Figure 6-13. Power Spectrum of Human Walking

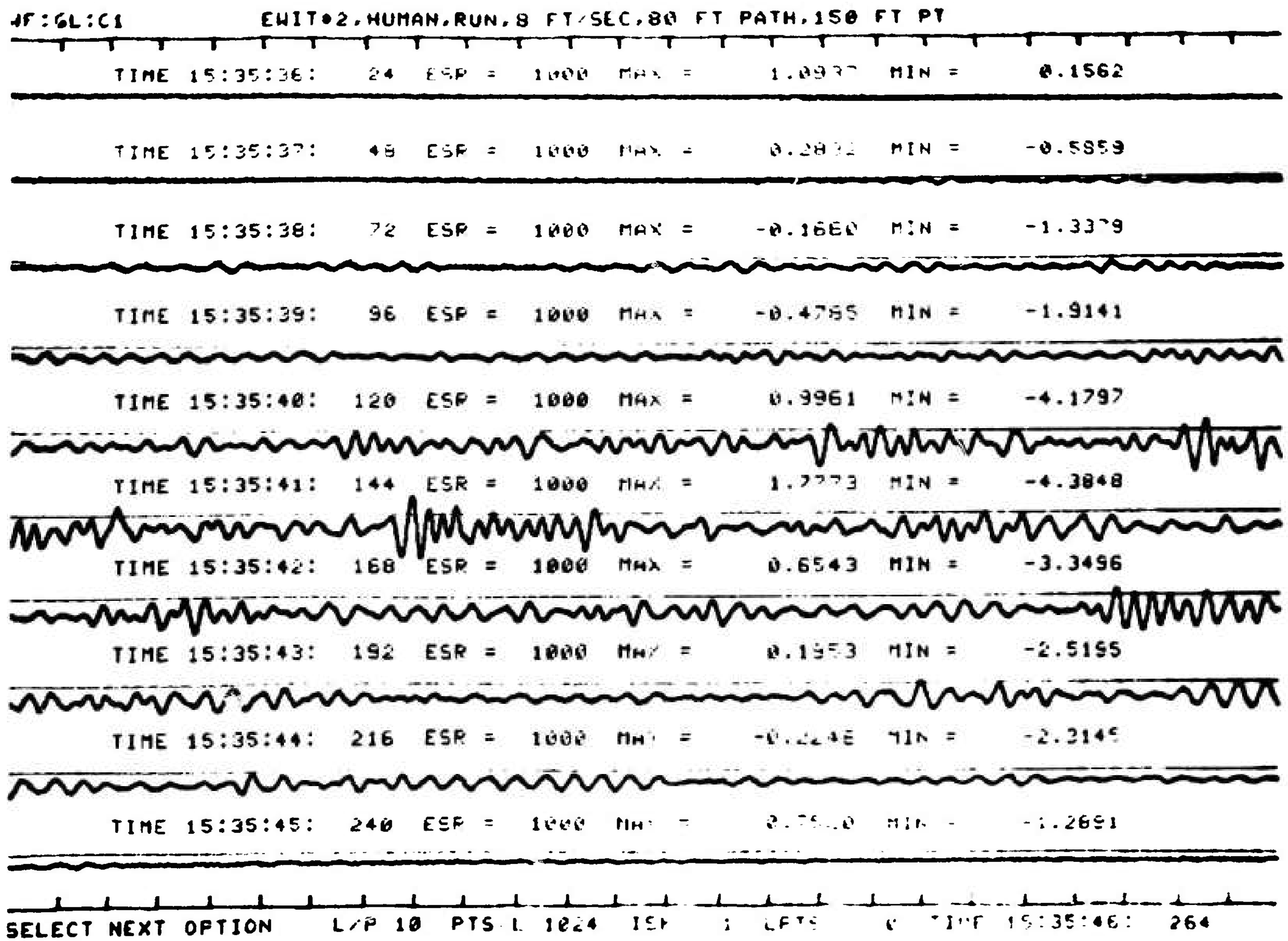

Figure 6-14. Analog Response of Human Running

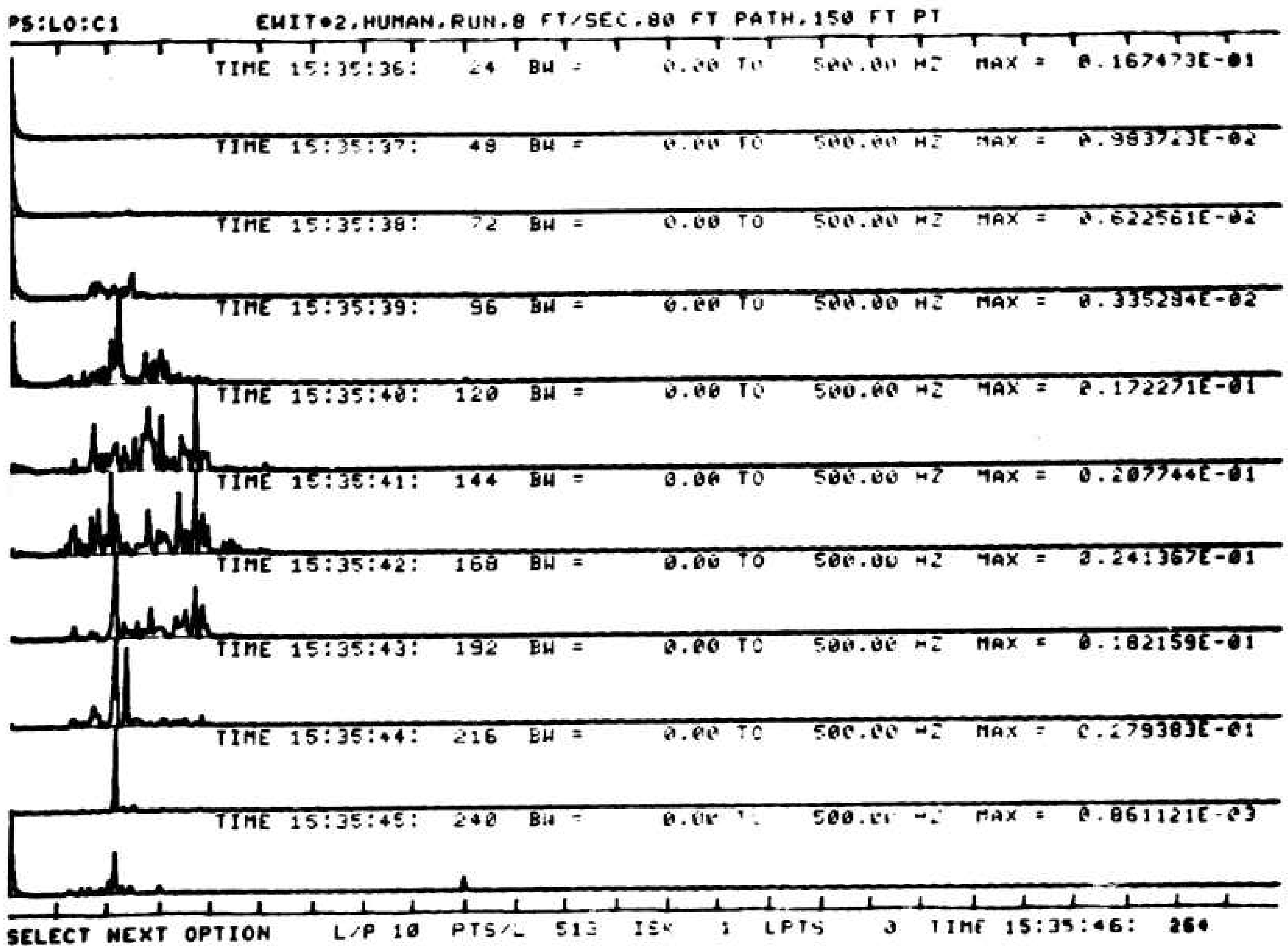

Figure 6-15. Power Spectrum of Human Running

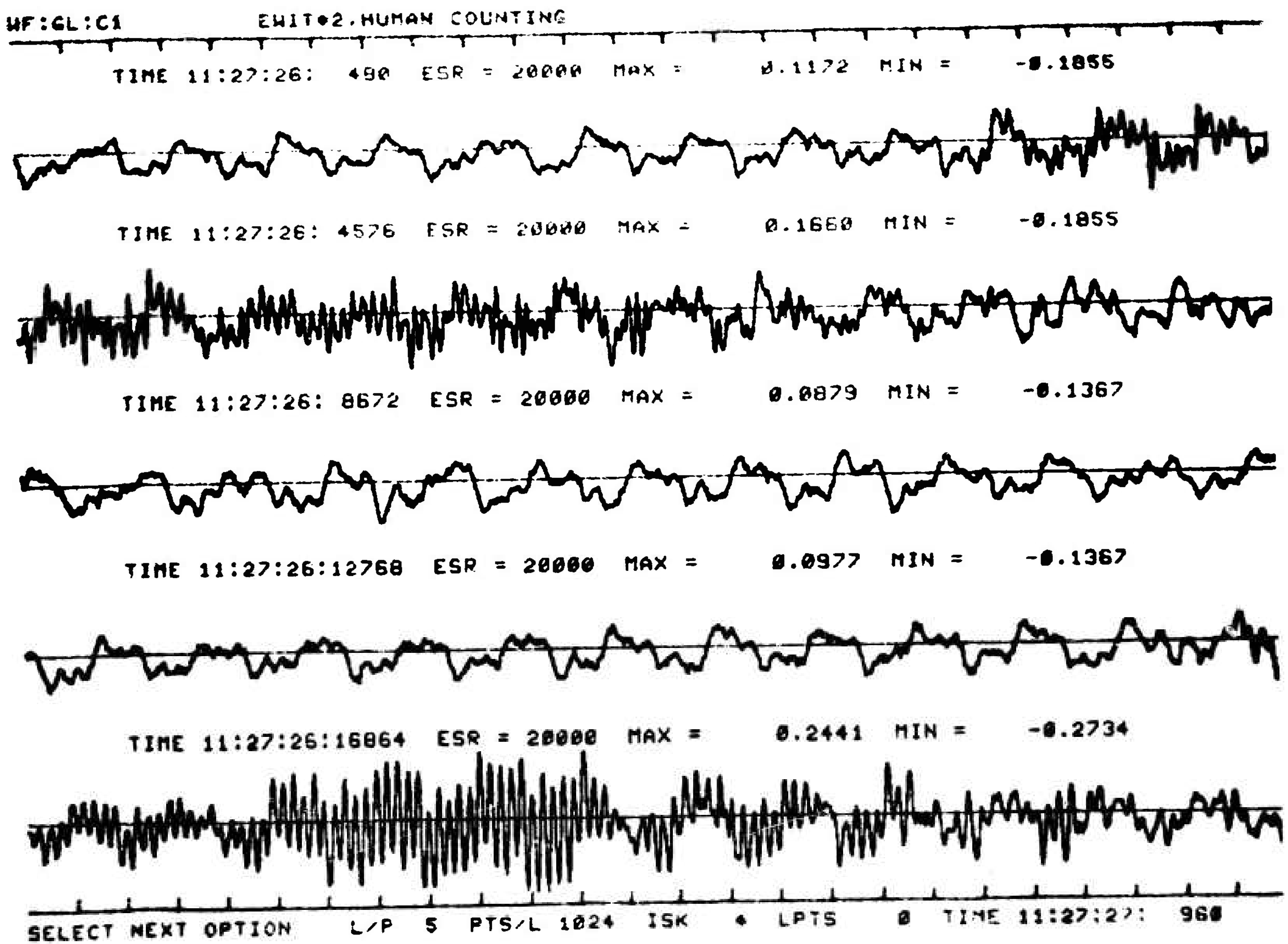

Figure 6-16. Analog Response of Human Counting

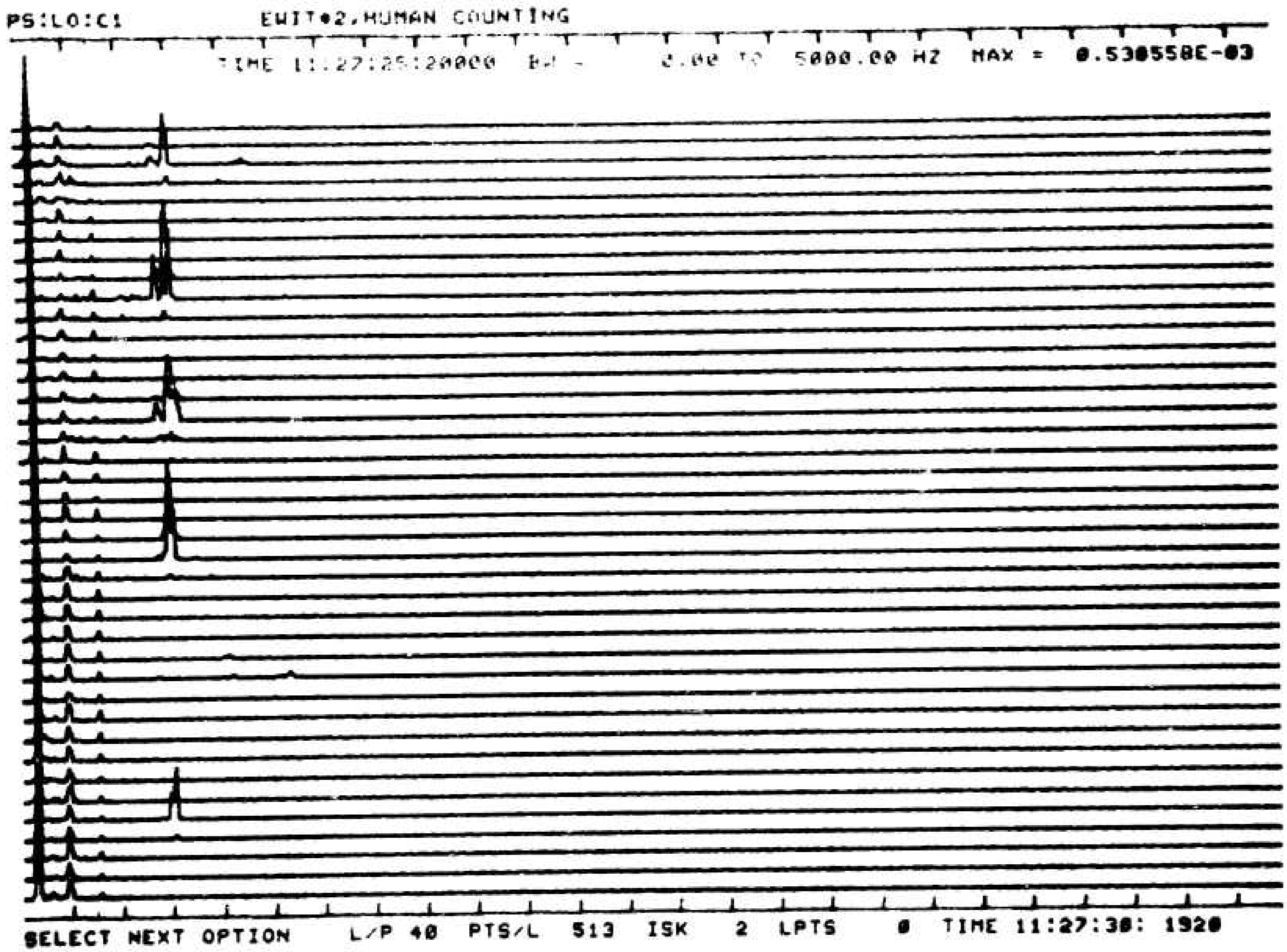

Figure 6-17. Power Spectrum of Human Counting

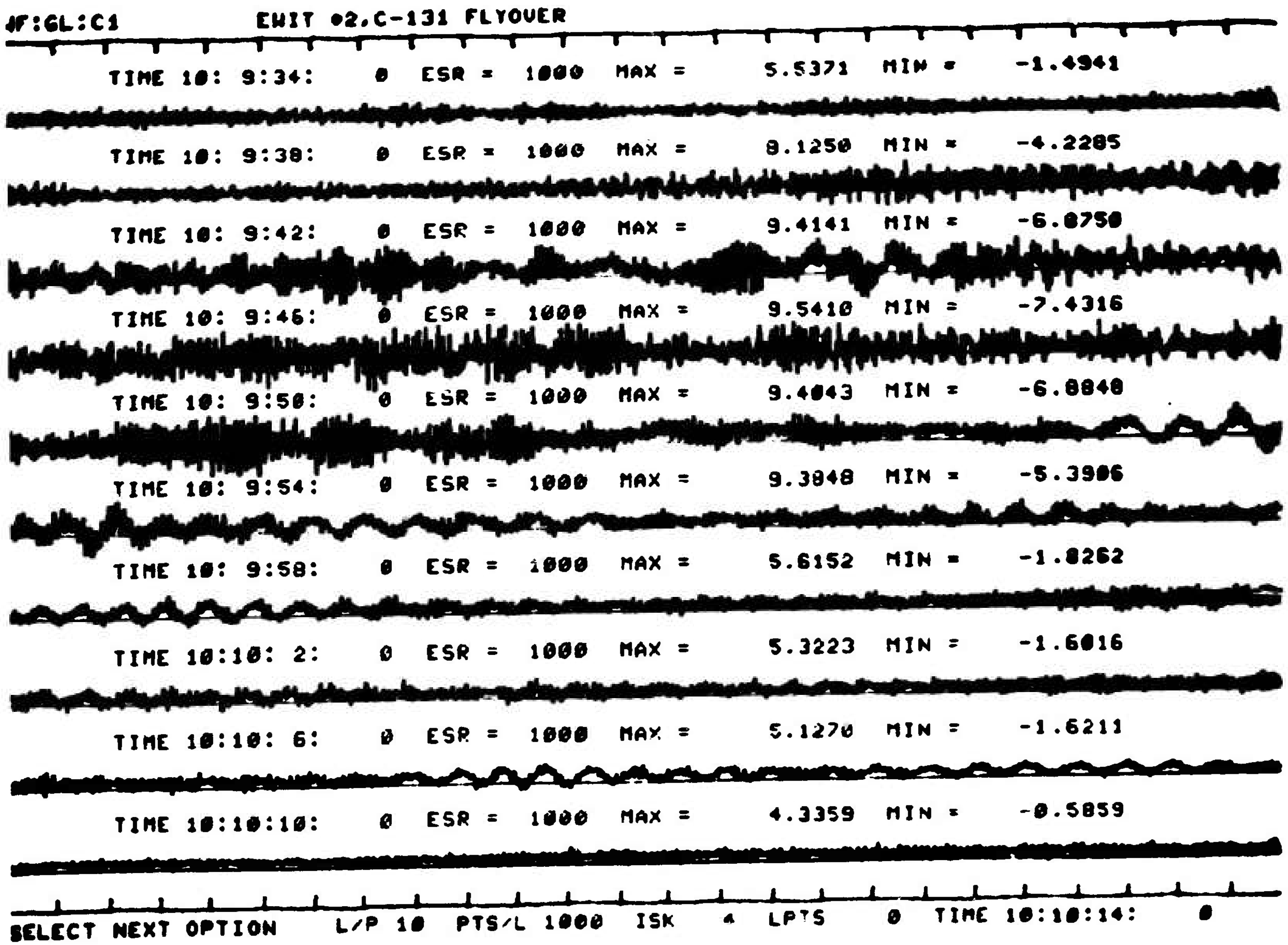

Figure 6-18. Analog Response of C-131

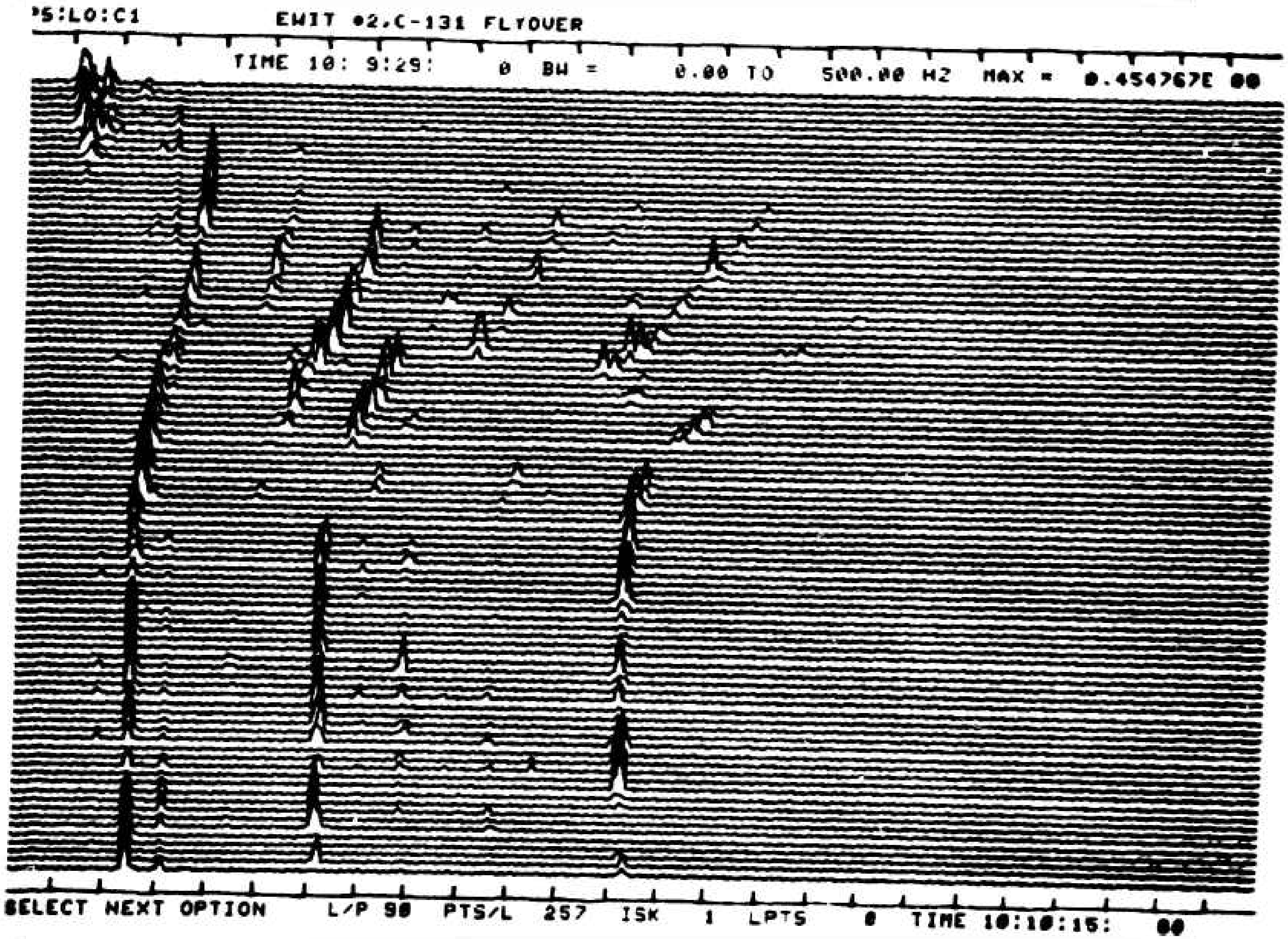

Figure 6-19. Power Spectrum of C-131

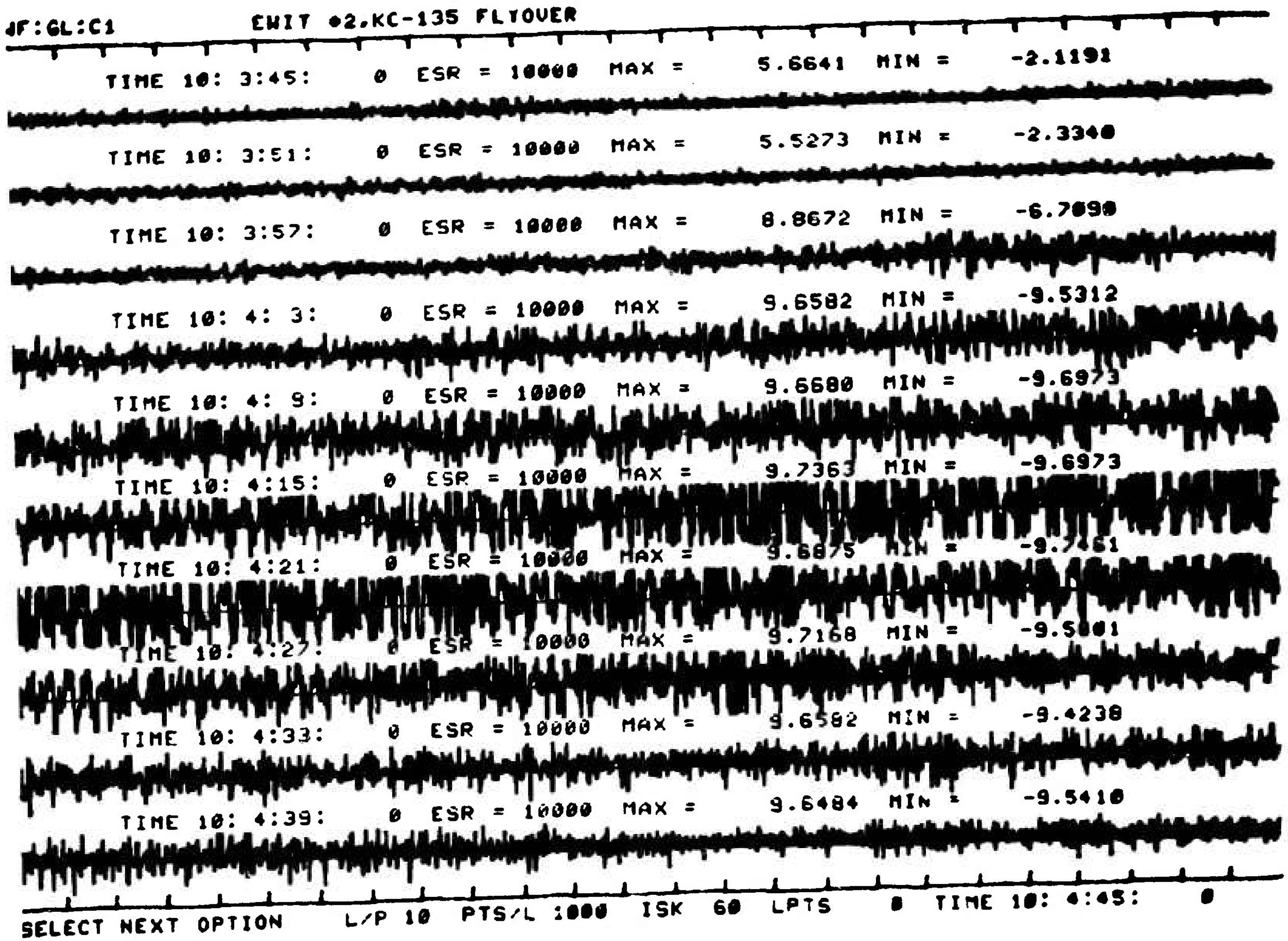

Figure 6-20. Analog Response of KC-135

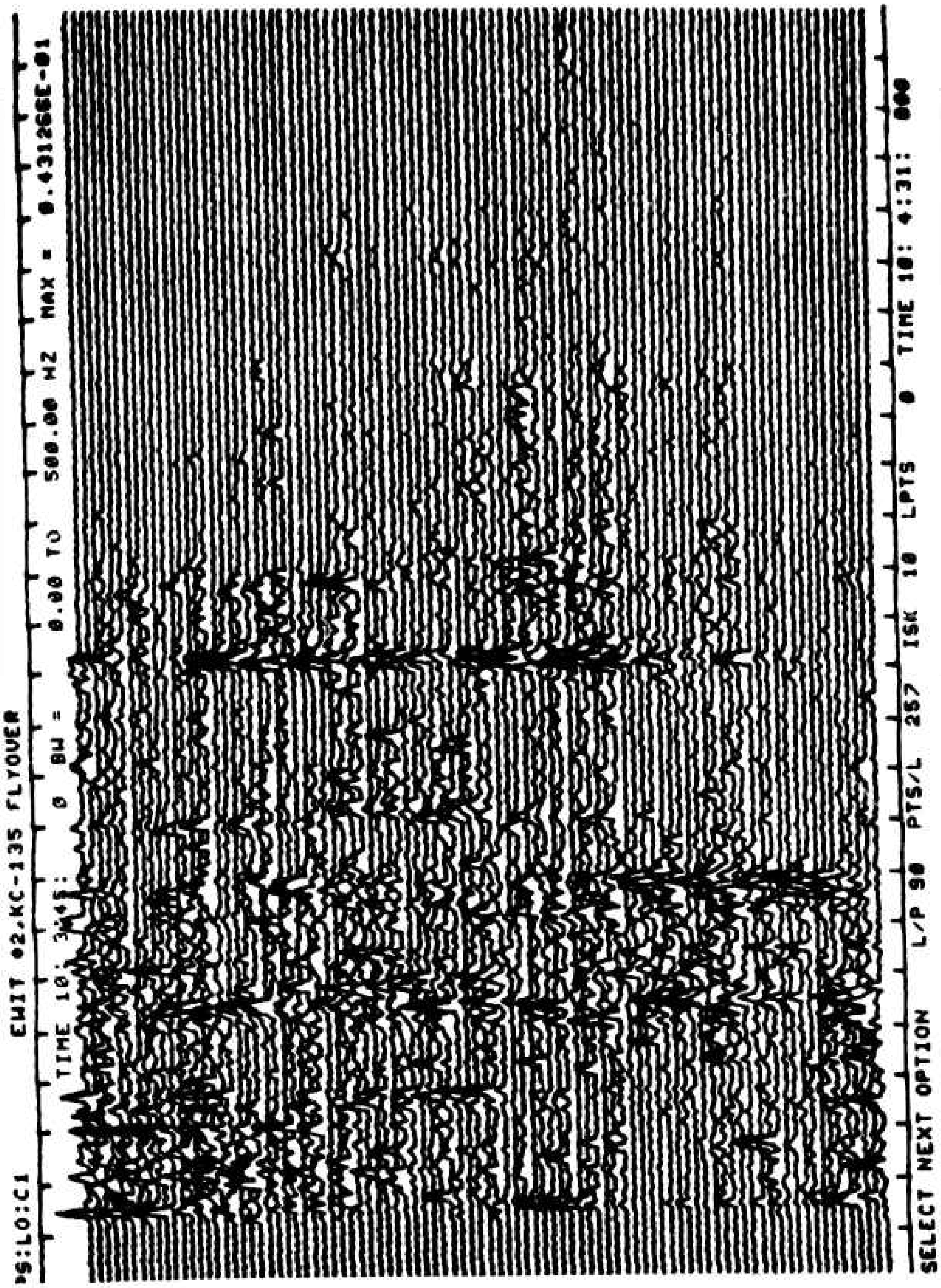

Figure 6-21. Power Spectrum of KC-135

6.3.5 Vehicle

A light weight jeep vehicle was driven 10 feet from, and parallel to, the WIT transducer. Figures 6-22 and 6-23 show the time domain and frequency domain responses. The spectral presentation shows a low frequency content as well as frequencies up to 120 Hz.

6.3.6 Rain

A comparison between moderate rain, light rain and background is shown in Figures 6-24 thru 6-29. The light rain and background spectra are quite similar except the light rain spectrum has a higher energy content at 30 Hz. The background spectrum has spectral lines at 180 and 300 Hz. These lines are nothing more than noise which is generated in the computer's A to D converter. The moderate rain spectrum shows a higher energy content over most of the frequency spectrum.

6.3.7 Thunder

Figures 6-30 and 6-31 show the WIT's response to thunder. The main energy content ranges from 25 Hz to 70 Hz.

6.3.8 Wind

Figures 6-32 and 6-33 show the WIT's response to wind, gusting to approximately 20 mph. The main frequency content is in a band from 60 to 90 Hz.

6.3.9 Other Phenomena

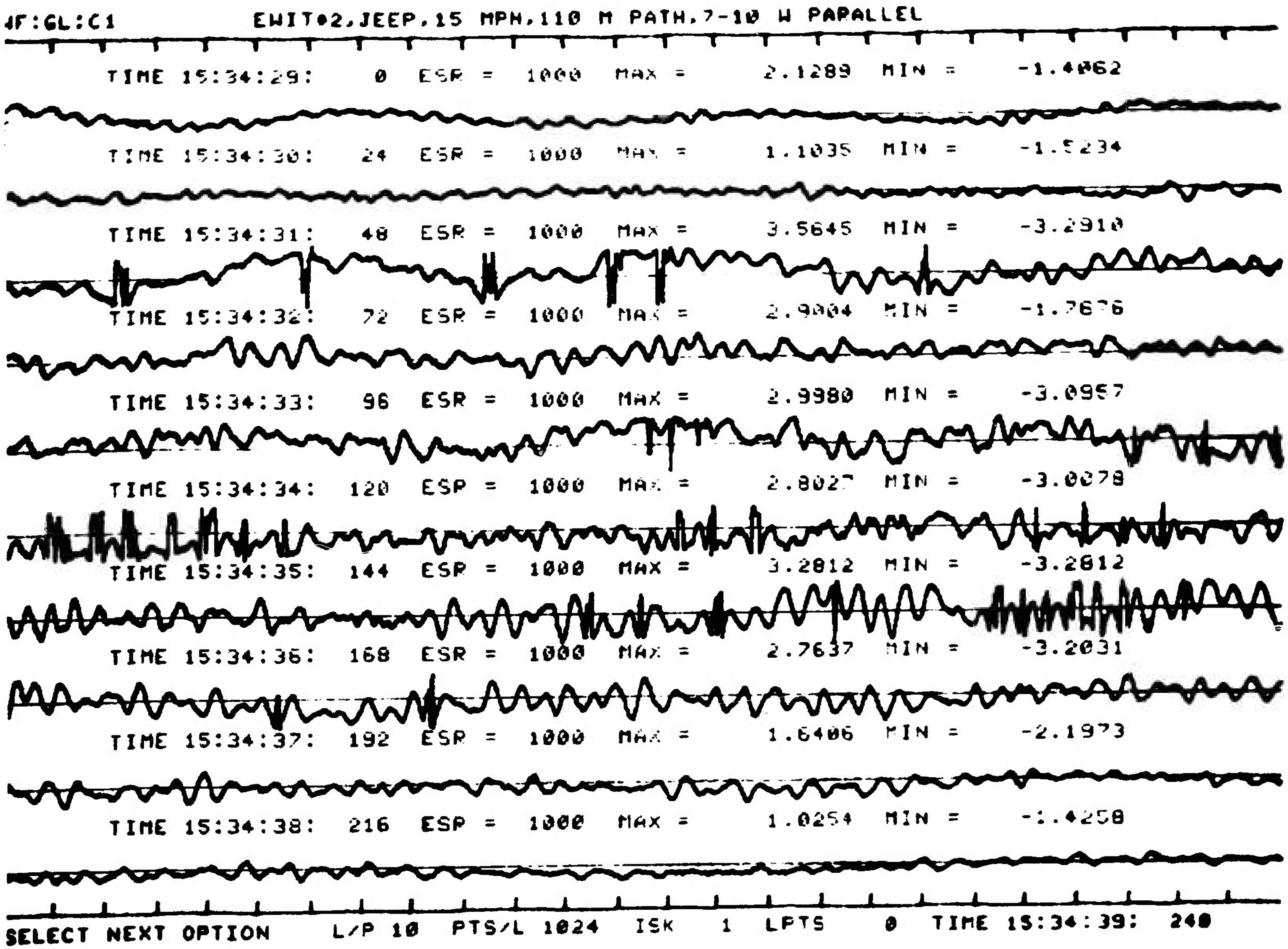

Figure 6-22. Analog Response of JEEP

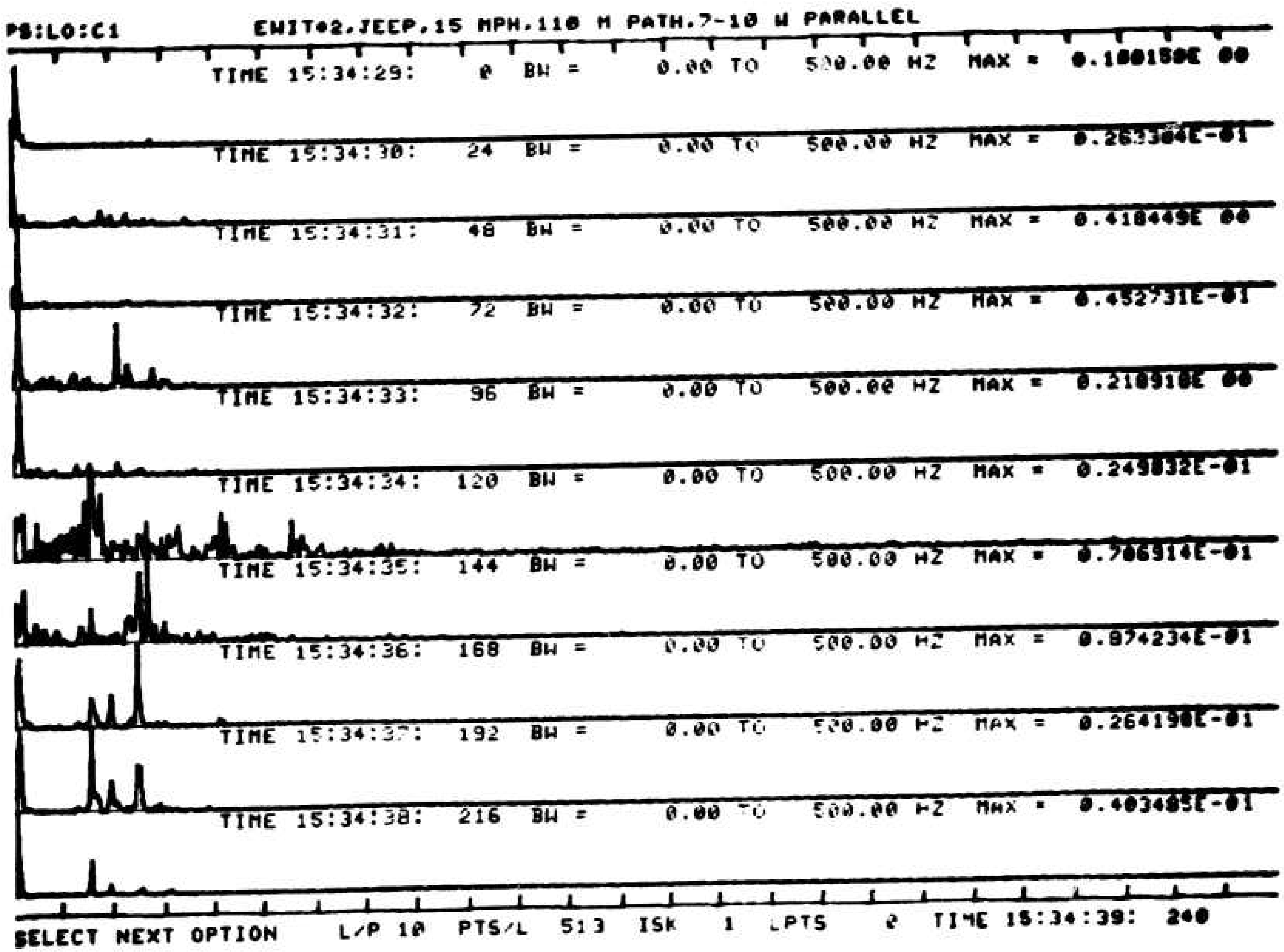

Figure 6-23. Power Spectrum of JEEP

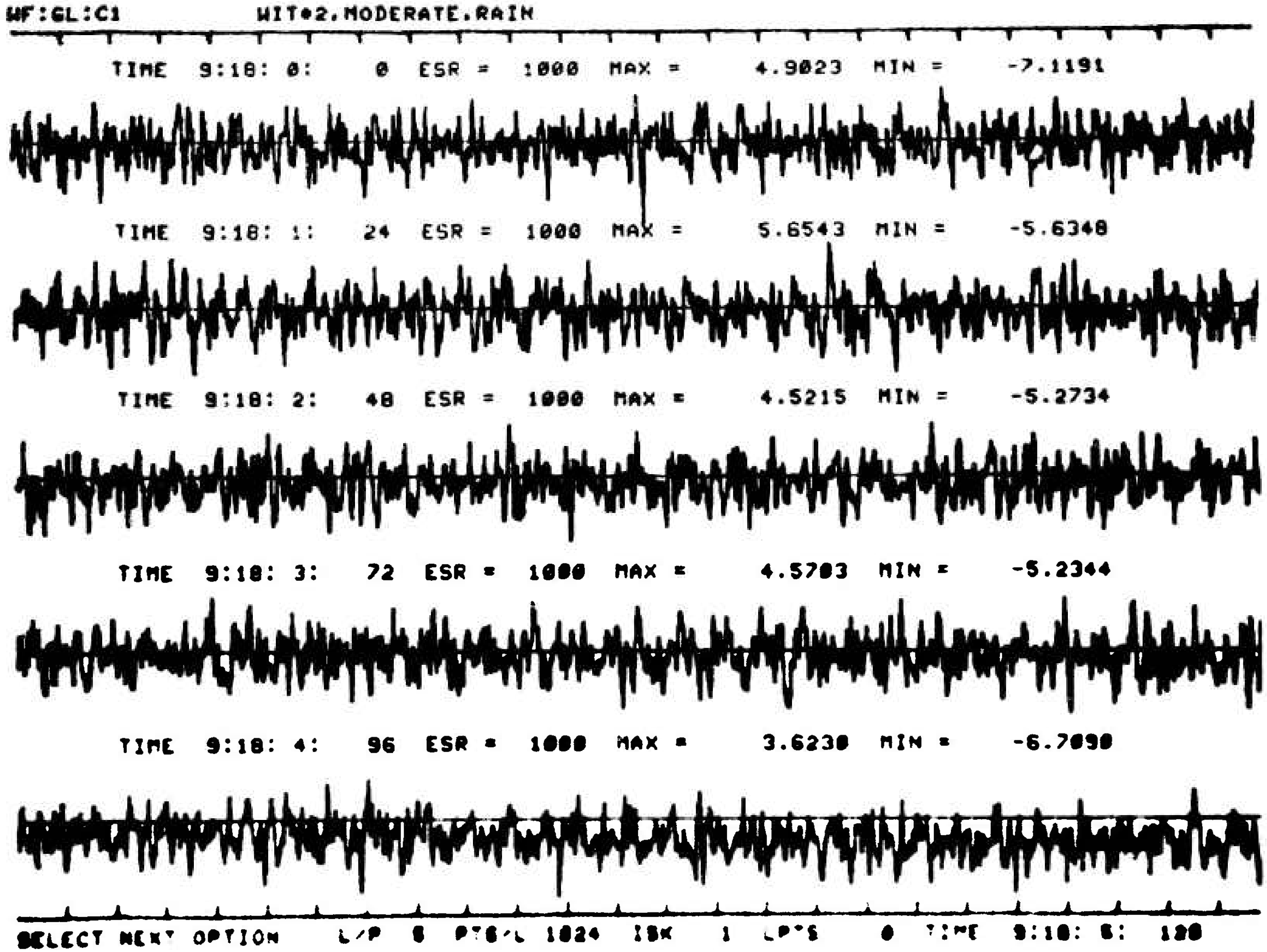

Figure 6-24. Analog Response of Moderate Rain

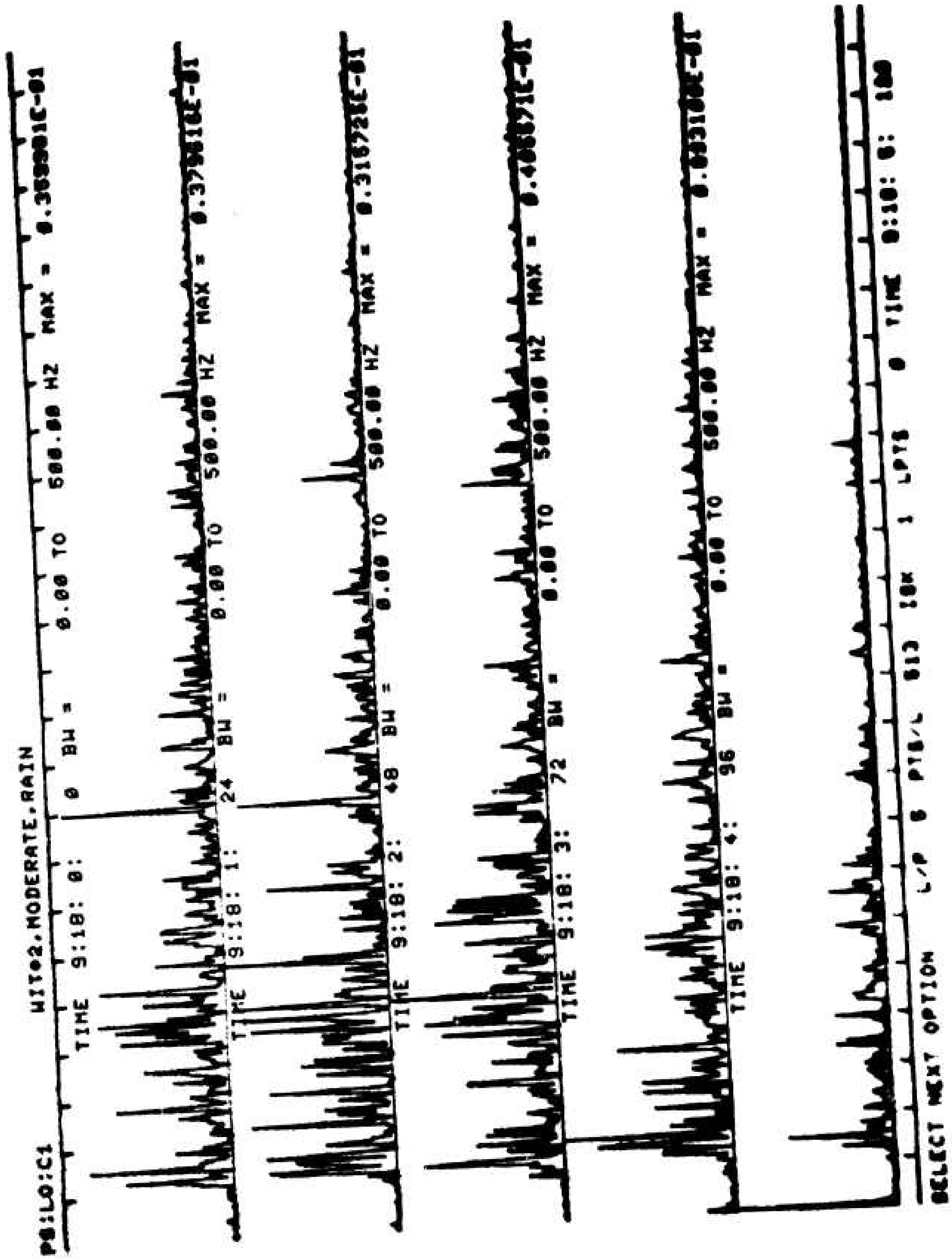

Figure 6-25. Power Spectrum of Moderate Rain

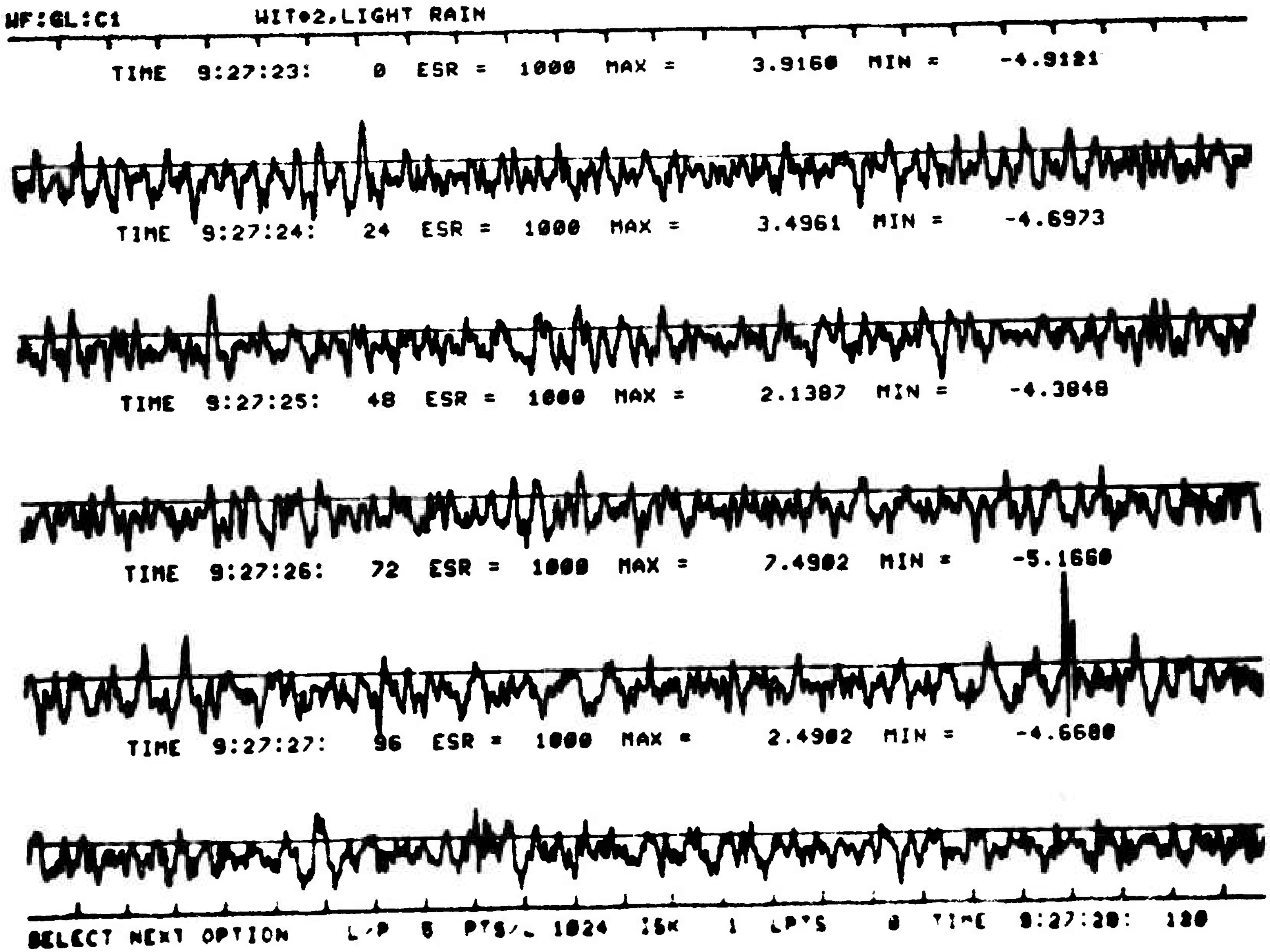

Figure 6-26. Analog Response of Light Rain

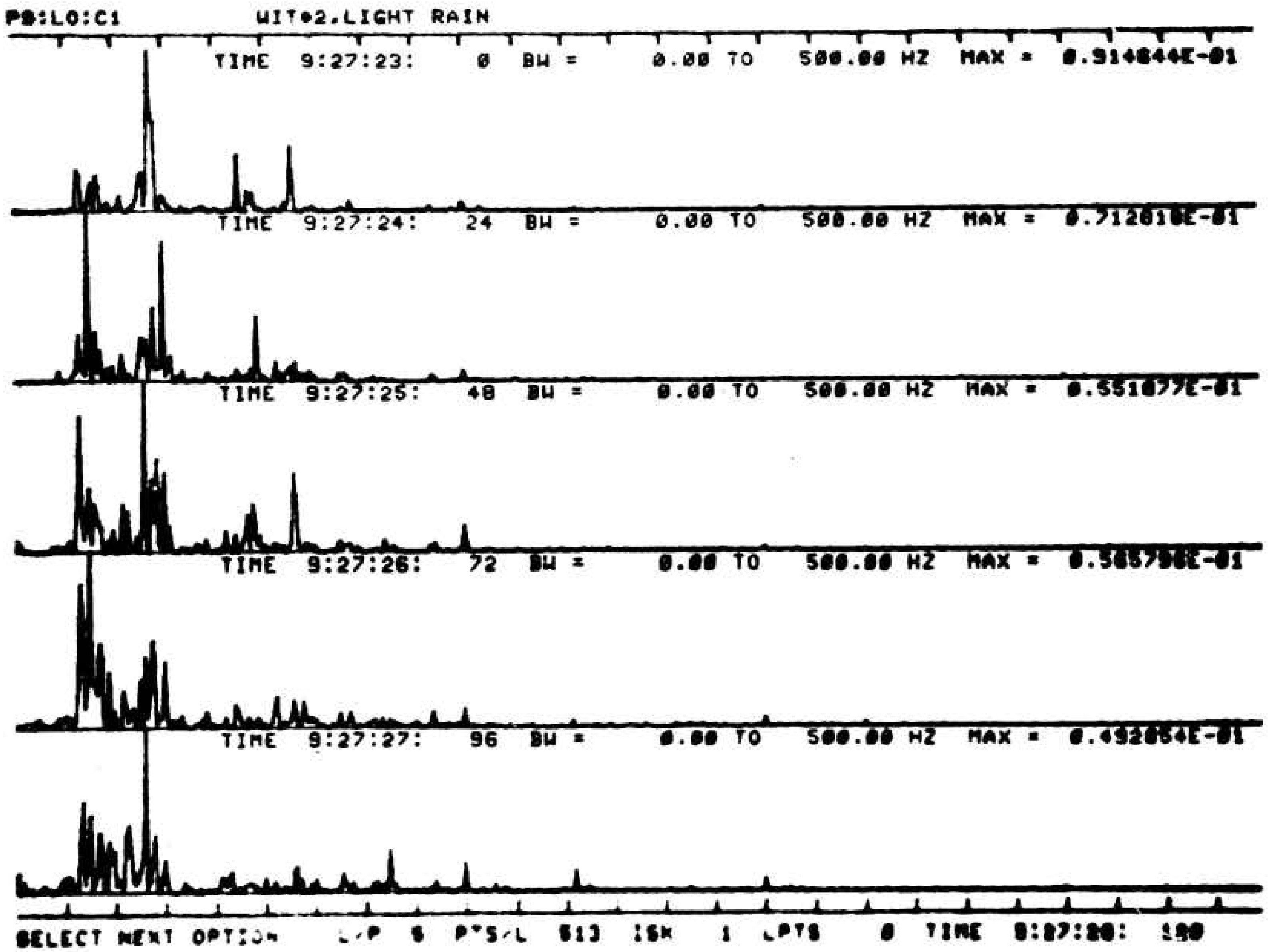

Figure 6-27. Power Spectrum of Light Rain

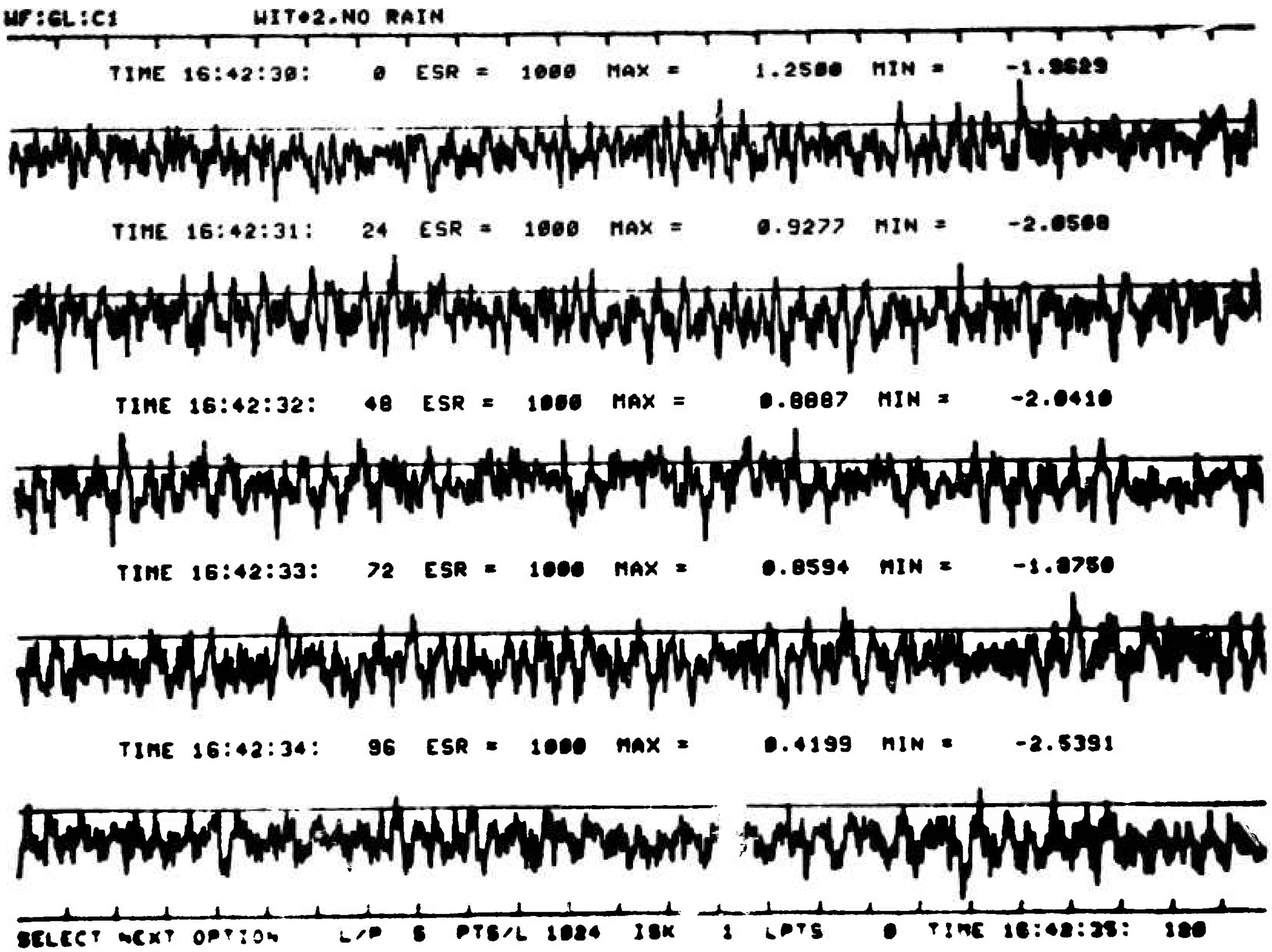

Figure 6-28. Analog Response of Background

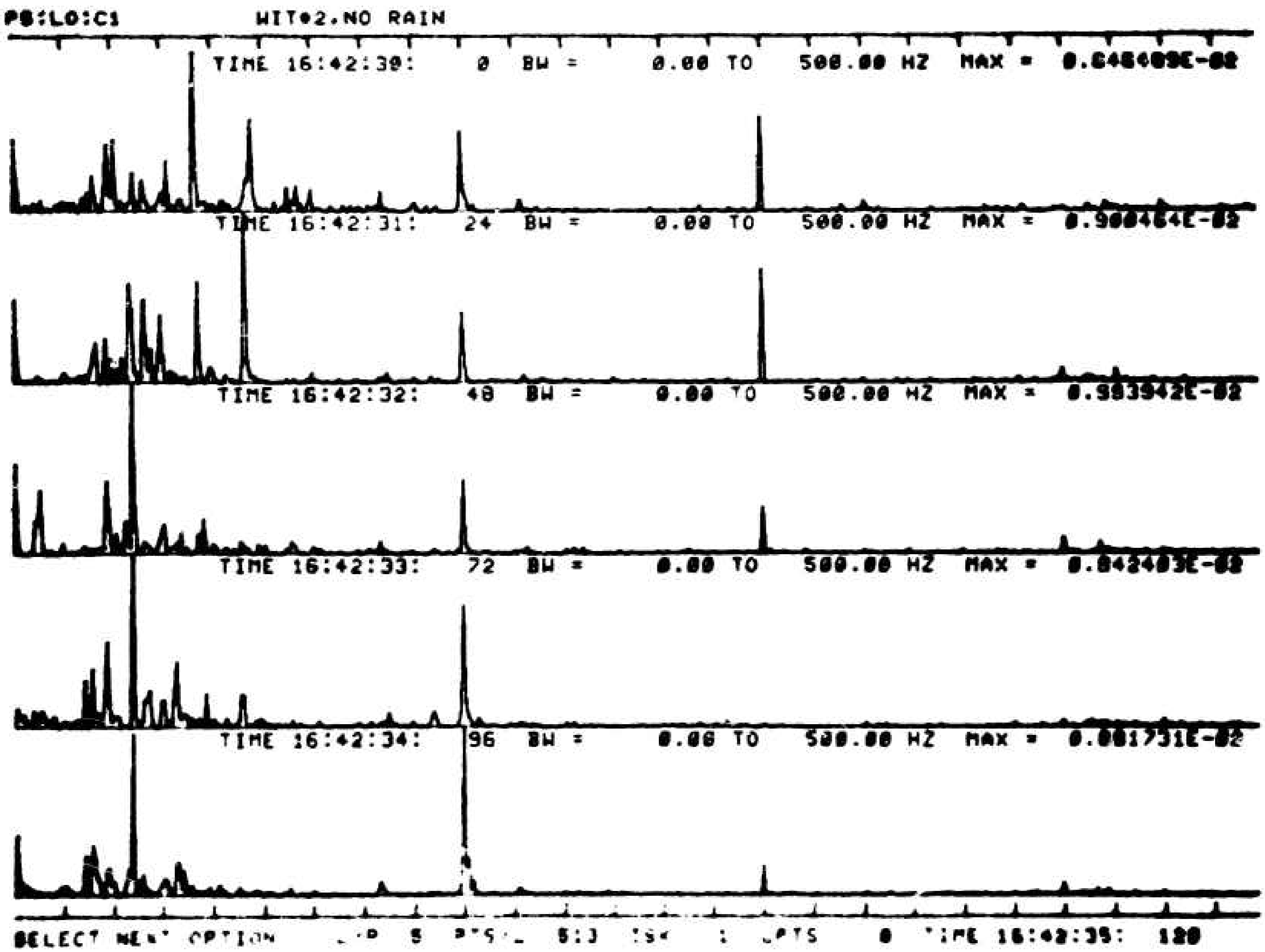

Figure 6-29. Power Spectrum of Background

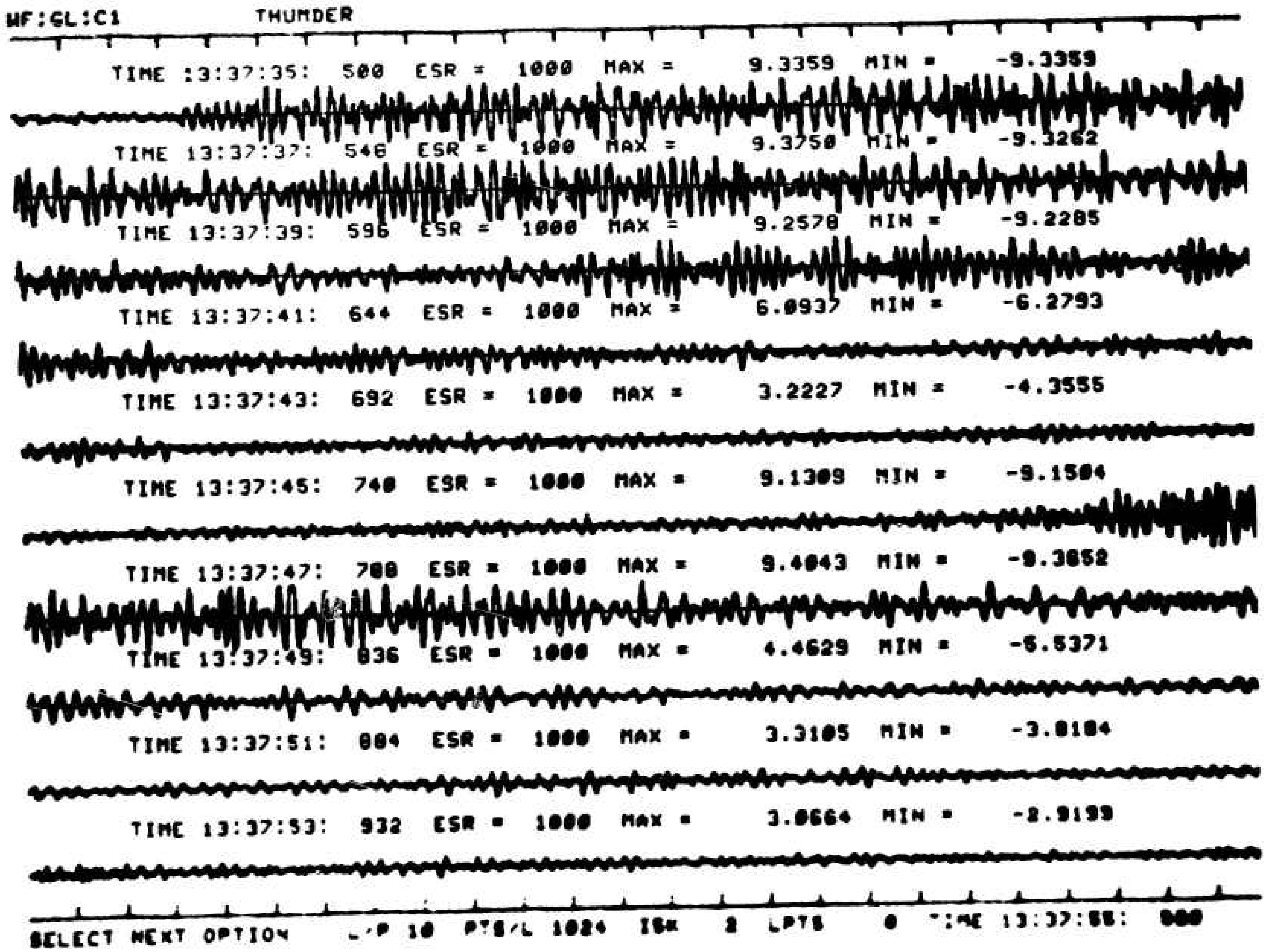

Figure 6-30. Analog Response of Thunder

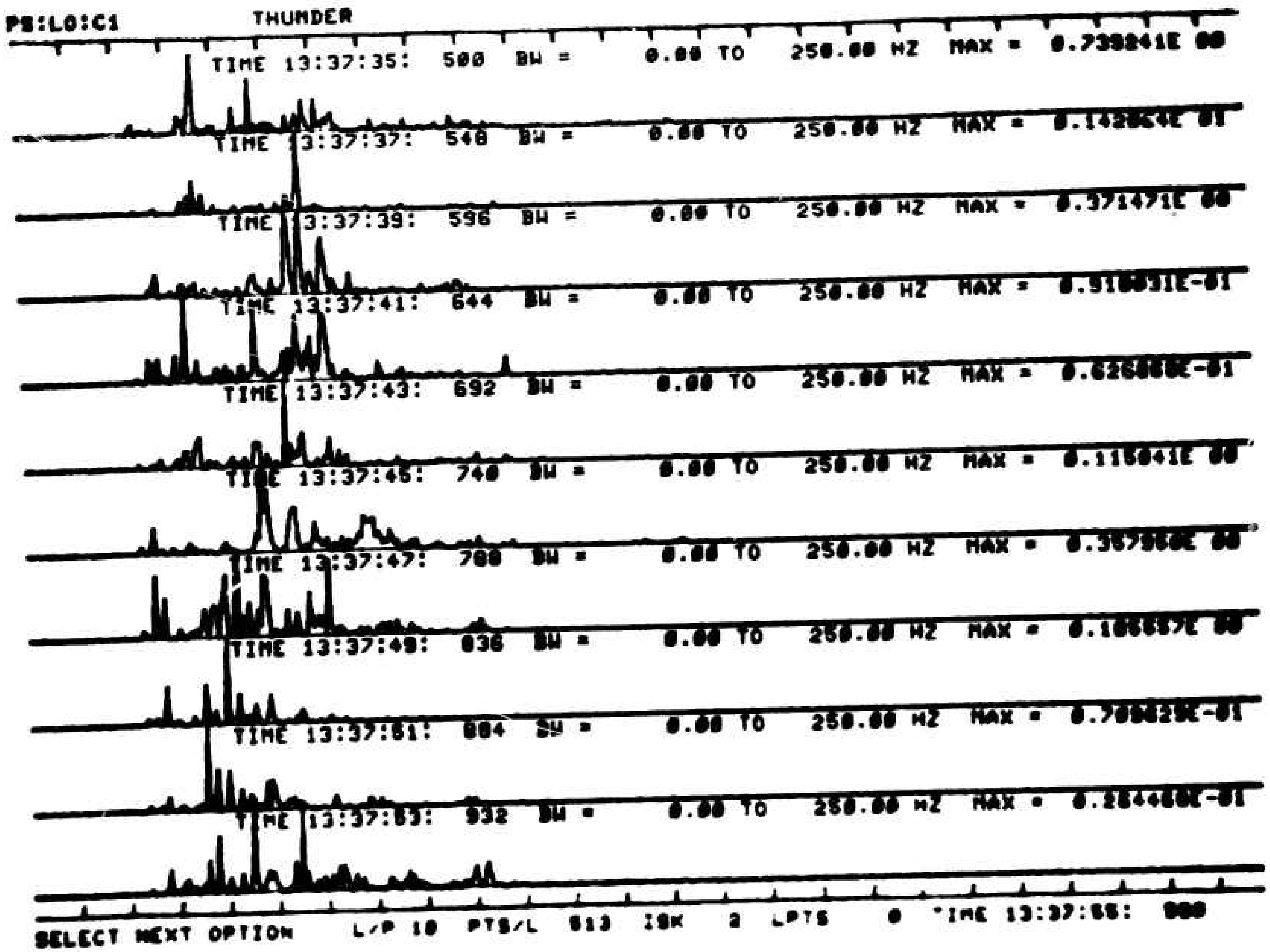

Figure 6-31. Power Spectrum of Thunder

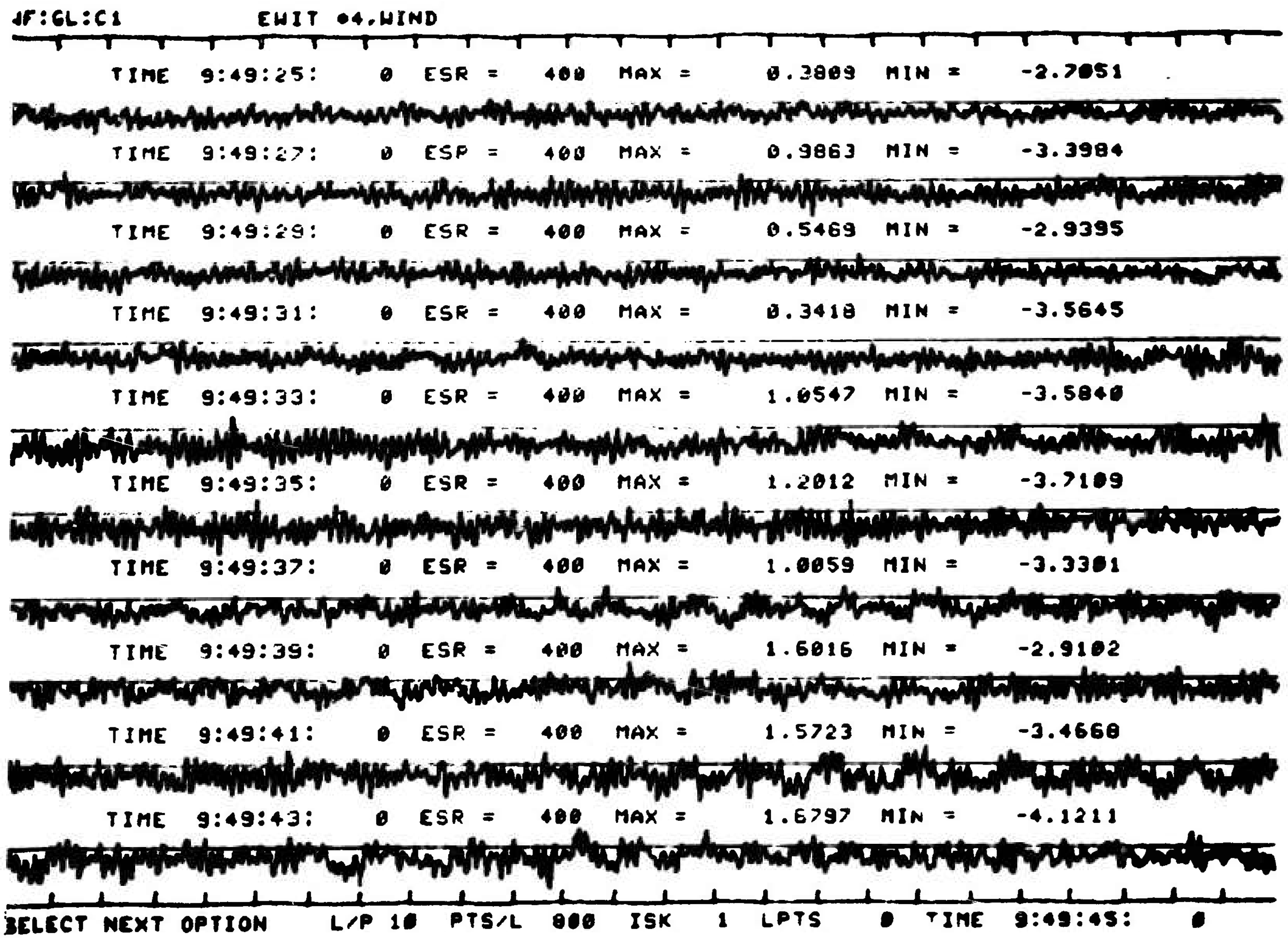

Figure 6-32. Analog Response of Wind

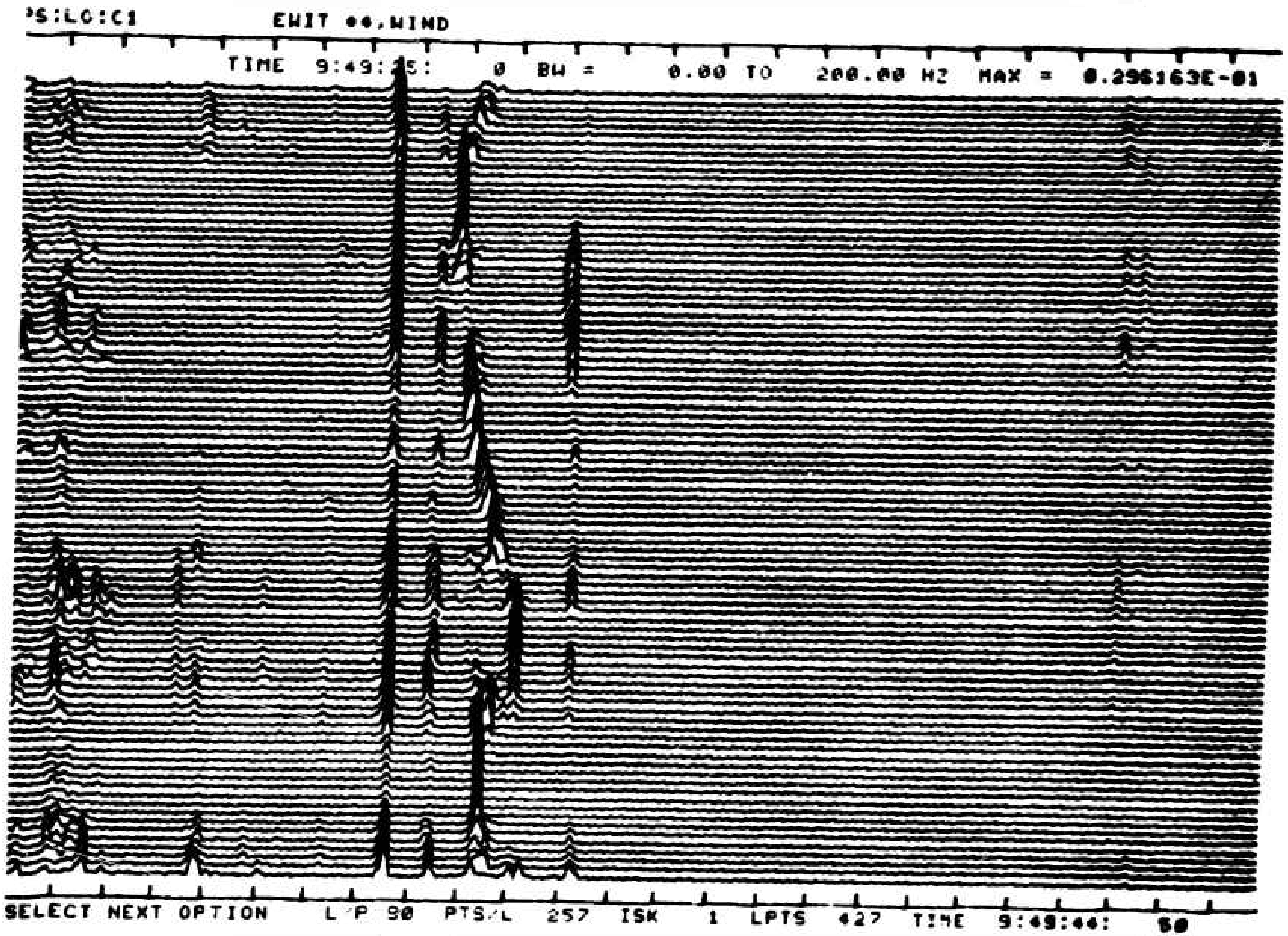

Figure 6-33. Power Spectrum of Wind

6.3.9.1 Noise Spikes

While conducting tests at Site 2D, large single noise spikes were noted. These noise spikes, which occurred at a random rate, were similar to the noise spikes described by Westinghouse in their report.[3] It was determined that the cause of these noise spikes was a sudden mechanical slippage of the wire with respect to the tube wall which resulted in a step function change in capacitiance. It was also determined that most of the noise spikes were thermally induced by changes in the weather which cause the ground to create mini-seismic disturbances (ground cracking in hot dry weather or heaving while freezing and thawing). These noise spikes were recorded on magnetic tape and an example is shown in Figures 6-34 and 6-35.

6.3.9.2 AM-PM Effects

Early in the test program it was decided that two or three positions on each transducer would be used as calibration points. At the start of each test, the drop hammer would be exercised at these positions so that a relative assessment of the ground conditions could be made on a daily basis. During these calibrations it was noticed that the amplitude of the output signal at one position changed from morning to afternoon. When the other calibration positions were checked the same effect was noticed at these positions.

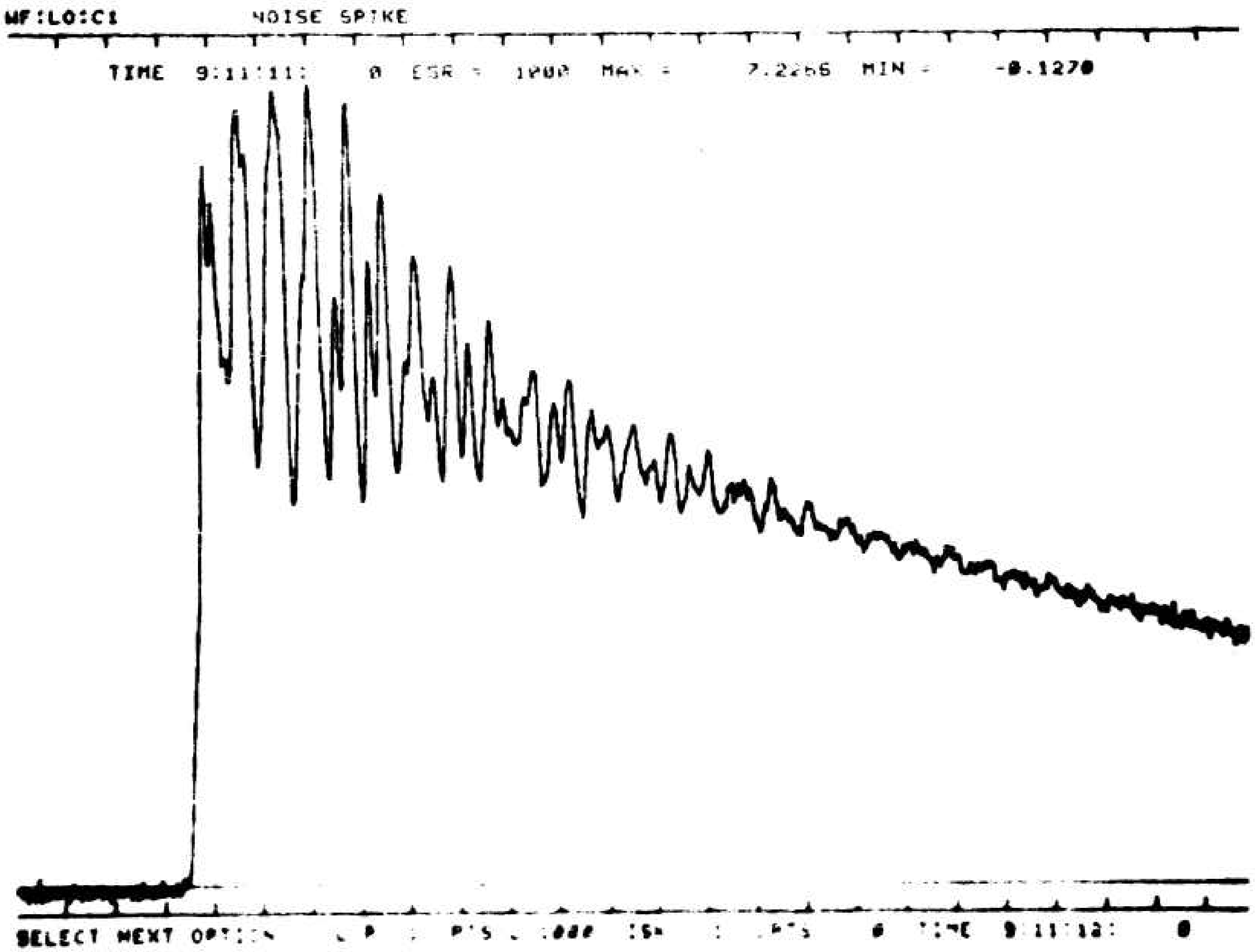

Figure 6-34. Analog Presentation of Noise Spike

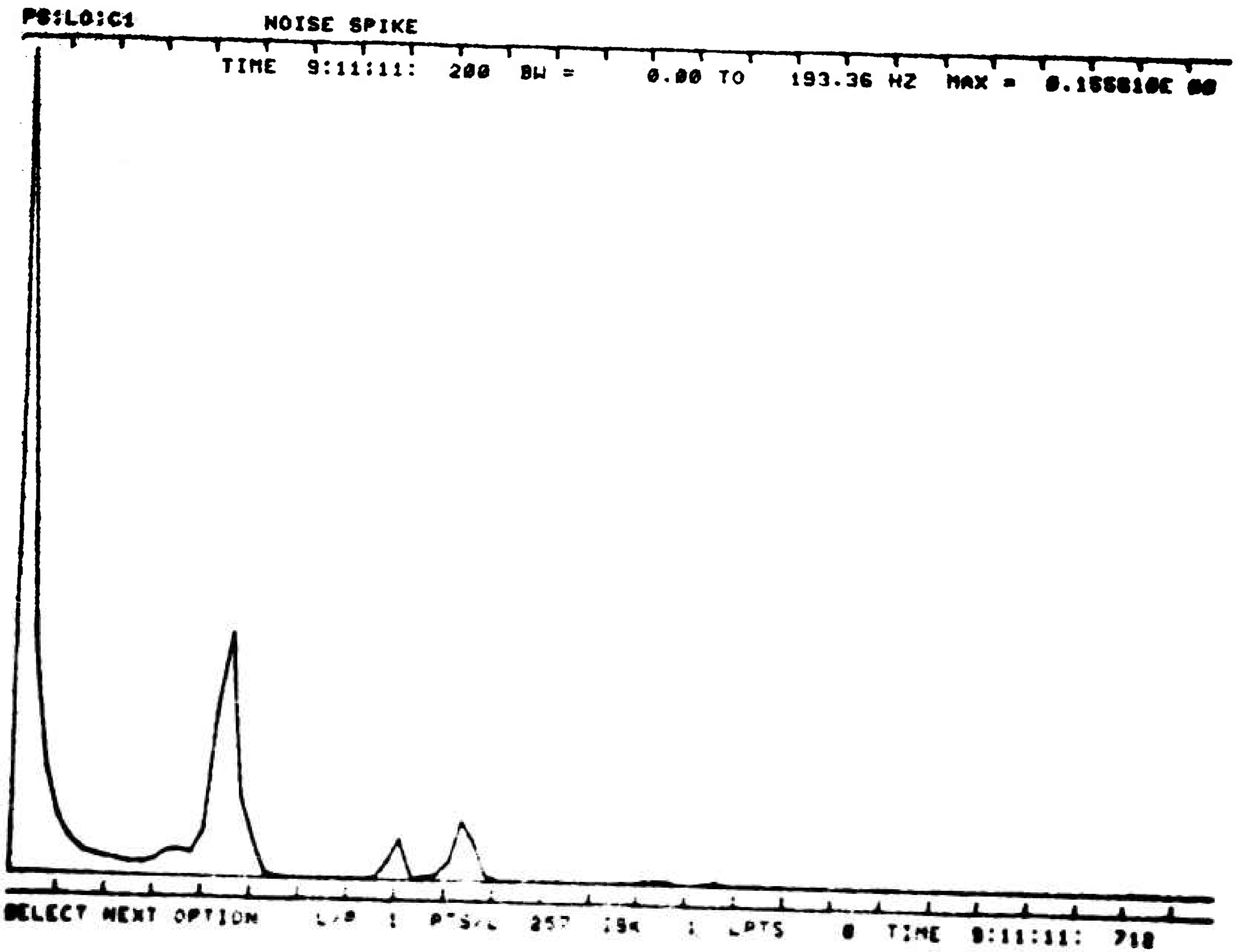

Figure 6-35. Power Spectrum of Noise Spike

It should be noted that the output signals were found to be relatively constant from morning to morning.

Table X provides samples of data taken in the morning and afternoon at several positions on two transducers. In the table it is interesting to note the 110-0 positions for both transducers. For WIT #1, the amplitude drops in the afternoon while for WIT #2, the amplitude rises in the afternoon. These positions are 5 feet apart in the sensor field. While further investigation in this area is needed, it is hypothesized that a thermal effect similar to that hypothesized for the noise spike is causing this change. As the day warms up or cools down, thermal expansion and contraction causes the touching points to shift which, in turn, will change the output. Since this is based on a random process, it is not unexpected that in some cases the amplitude will rise and in others it will fall.

6.3.9.3 Excitation of Two WITS by a Single Source

The objective of this task was to determine the difference in frequency response from two WIT transducers which were simultaneously excited by a single source. An intrusion path was selected that was directly between two parallel WIT transducers that were buried 9 inches deep and 5 feet apart. Figures 6-36 and 6-37 are the power spectra from the two WIT transducers, designated WIT 1 and WIT 2

TABLE X

AM-PM EFFECTS ON WIT OUTPUT VOLTAGE

LINE POSITION	VOLTS$_{P-P}$ SINGLE CYCLE			
	AM		PM	
	DROP 1	DROP 2	DROP 1	DROP 2
WIT 1				
110 - 0	9.4	6.4	3.2	3.6
120 - 0	3.0	2.8	4.4	4.0
210 - 0	1.2	1.6	2.6	1.4
220 - 0	2.6	2.3	4.2	4.2
WIT 2				
110 - 0	4.5	5.0	8.1	8.5
120 - 0	6.4	6.0	9.6	8.4

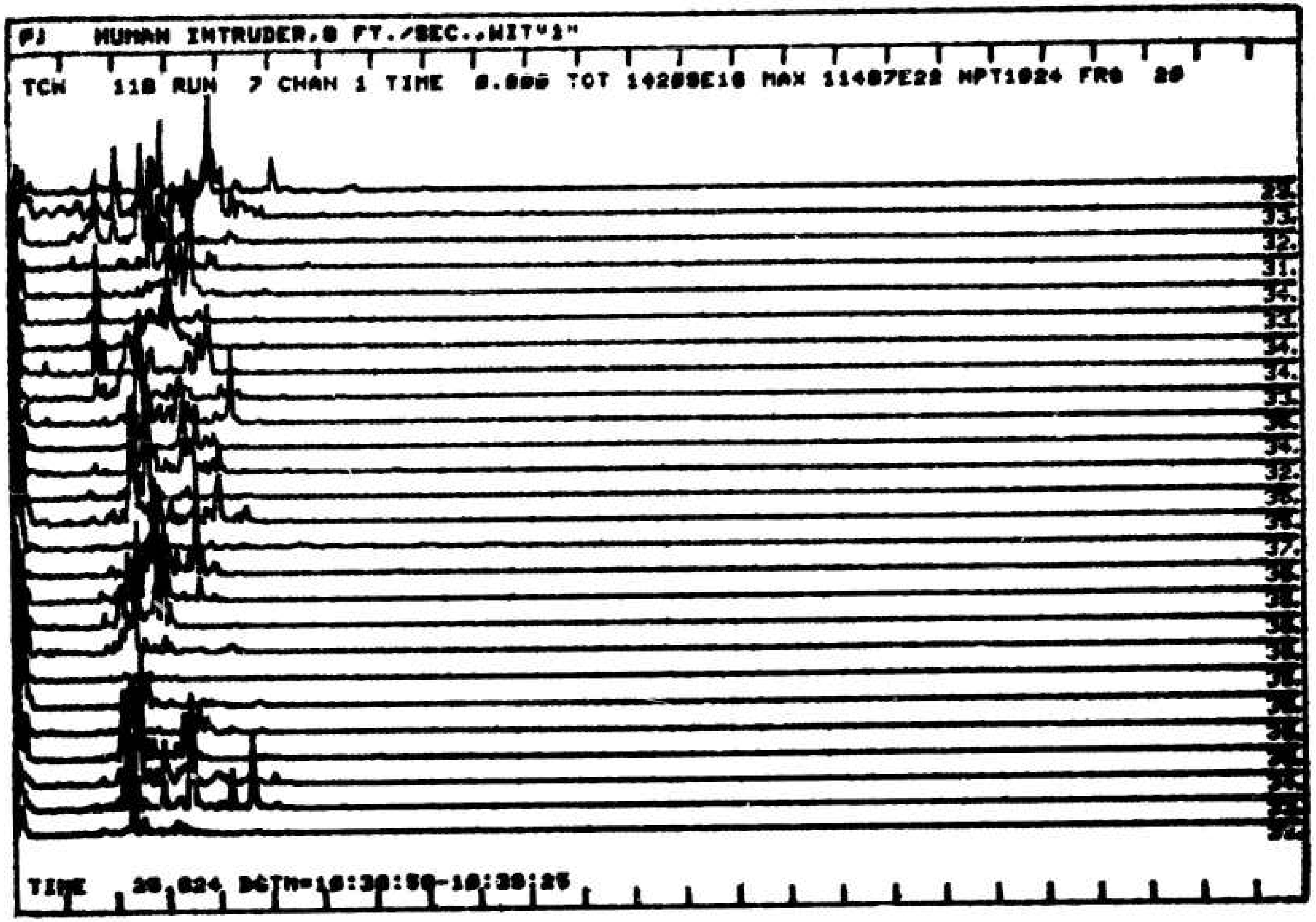

Figure 6-36. Power Spectrum of Human Running (WIT #1)

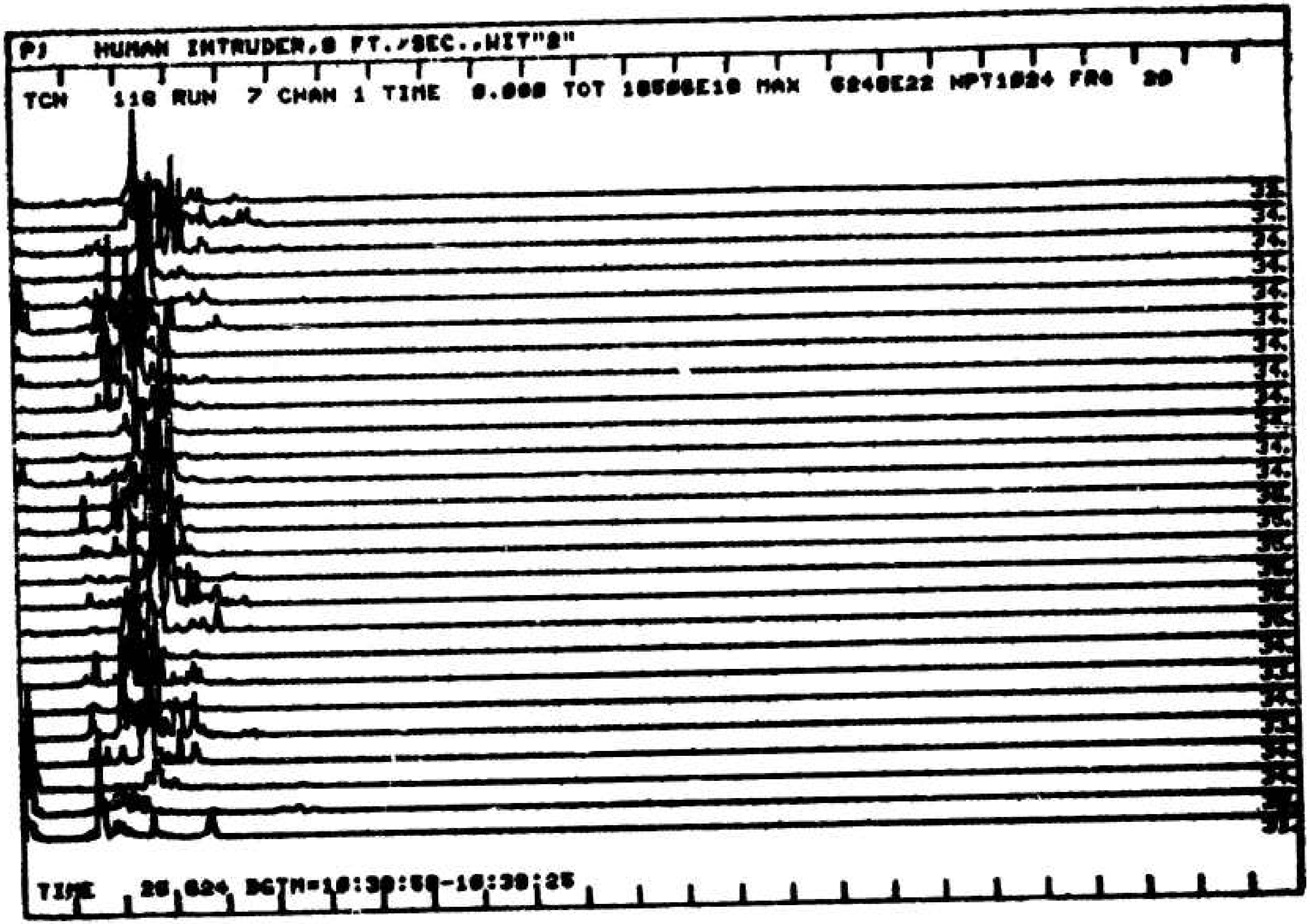

Figure 6-37. Power Spectrum of Human Running (WIT #2)

respectively, which were simultaneously excited by a human running along this path at an approximate speed of 8 feet/sec.

An analysis of the data shows that the energy for WIT 1 is concentrated in the 40 to 80 Hz frequency band. It also shows some energy present below 2 Hz. WIT 2, on the other hand, has its main concentration in the 35 to 55 Hz band and has less energy below 2 Hz than WIT 1. It is postulated that the variations between the two transducers are due mainly to the differences in the geometry (touch points) of the wire within each tube although some contribution may result from the difference in the seismic propagation channels that exist between the intrusion path and the two transducers.

6.4 Stability

Throughout the winter evaluation period, daily logs were kept on the local environmental conditions. When major changes were noted, human crossings were made and recorded on magnetic tape.

Figures 6-38 thru 6-45 show a comparison of crossings for various snow depths and frost levels. The crossings were made at a rate of 3 ft/sec and were made along the same intrusion path.

Figure 6-39 shows the spectrum of a human intruder when the snow depth and frost level were 11 inches and 16 inches respectively. The energy content ranges from 25 Hz

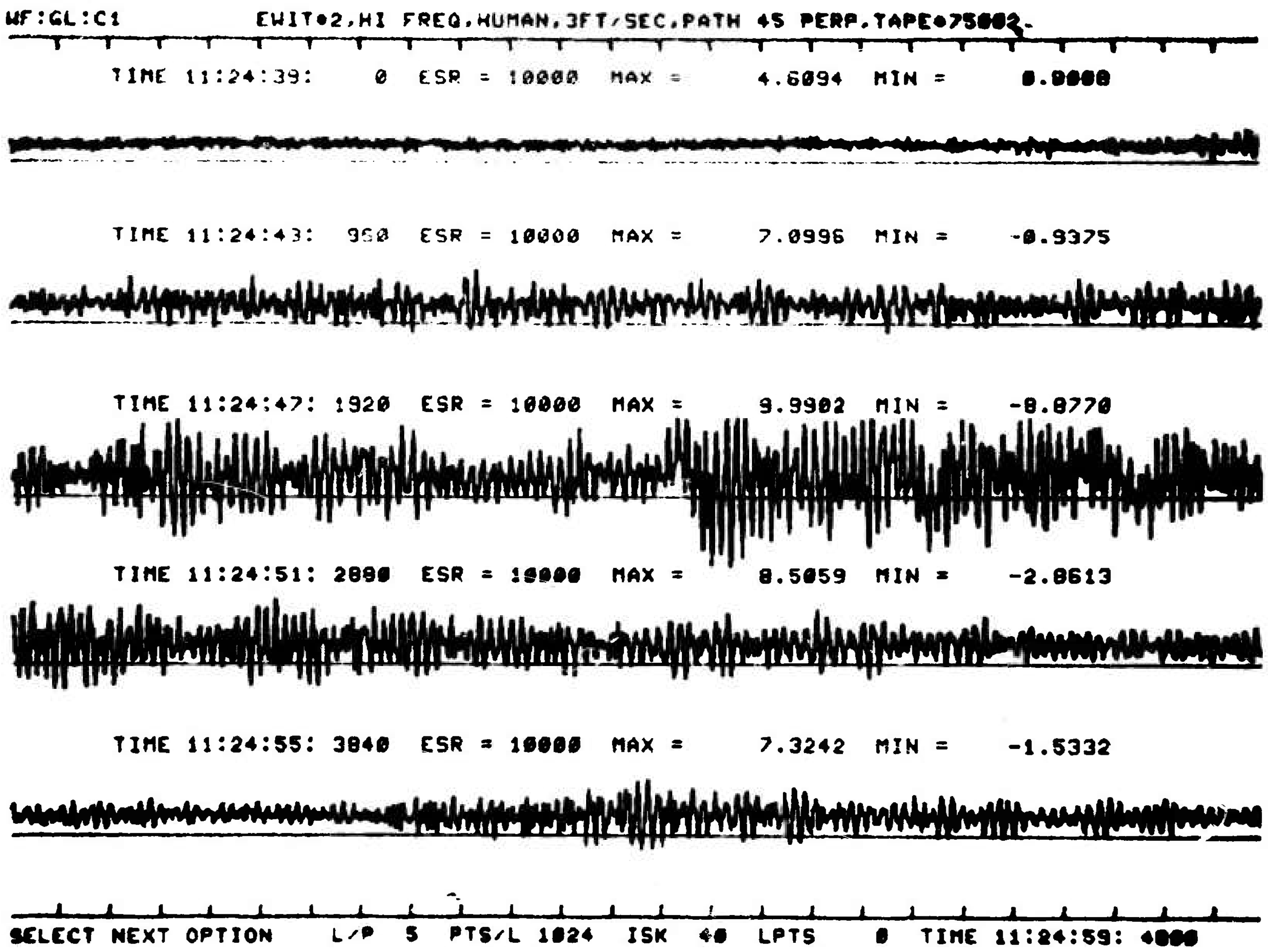

Figure 6-38. Analog Response of Human Walking (16" Frost, 11" Snow)

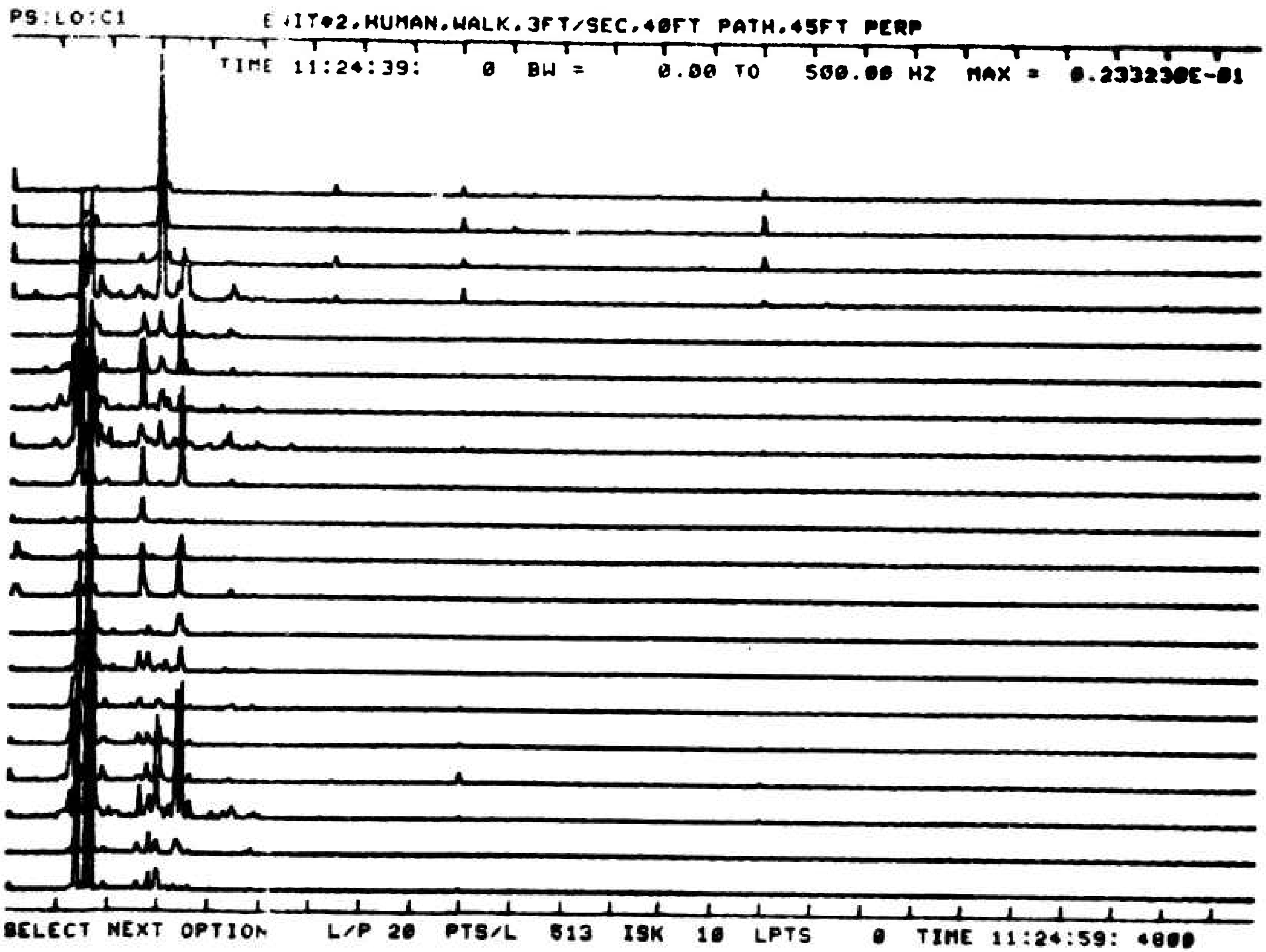

Figure 6-39. Power Spectrum of Human Walking (16" Frost, 11" Snow)

to 70 Hz with the greatest concentration in the 25 to 35 Hz range.

Figure 6-41 shows the spectrum of a human intruder with a 5 inch snow depth and a 13 inch isothermal layer. The energy content ranges from 22 Hz to 90 Hz with greatest concentrations in the 22 to 30 Hz range.

Figures 6-43 and 6-45 show the spectrums of a human intruder with the ground thawed and 1 inch of snow cover versus the ground thawed and no snow cover respectively. The spectrum for the 1 inch of cover shows the main concentration of energy to be in the 25 to 45 Hz range. The spectrum for the no snow condition shows the main concentration of energy to be in the 15 to 30 Hz range.

It should be noted that, for a thaw/no snow condition, the main concentration of energy is in the 15 to 30 Hz range. This main concentration of energy shifts upward in frequency as the frost and snow depths deepen. The 11 inch snow depth/16 inch frost level has a concentration of energy in the 25 to 35 Hz range. A loss in gain of approximately 24 db was noted for 11 inch snow depth/16 inch frost level. However, the background noise was also reduced by 20 db resulting in only a slight change in the signal to noise ratio. It is felt that a simple AGC circuit that tracks the noise may be able to maintain the overall performance relatively constant.

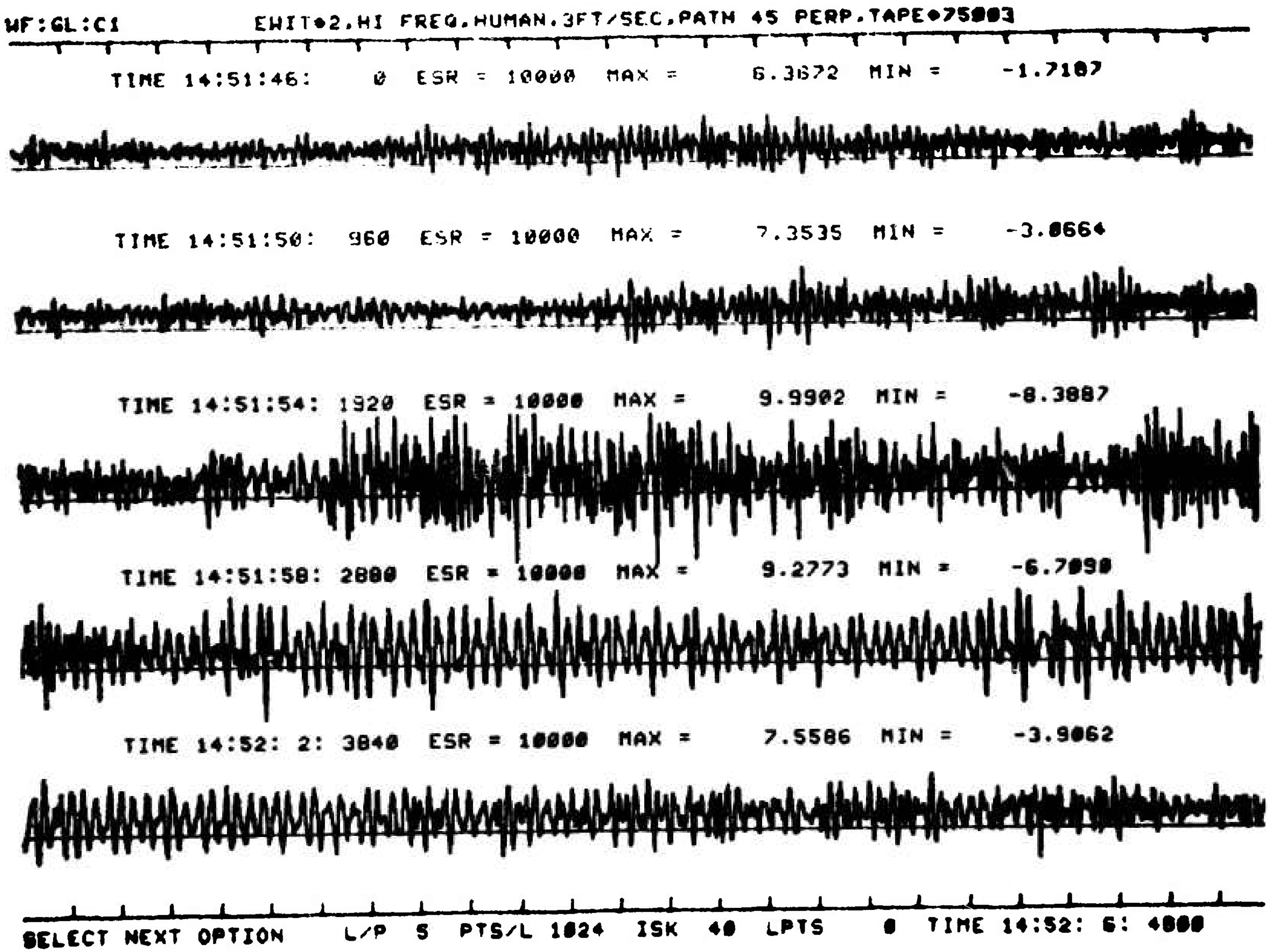

Figure 6-40. Analog Response of Human Walking (13" Isothermal, 5" Snow)

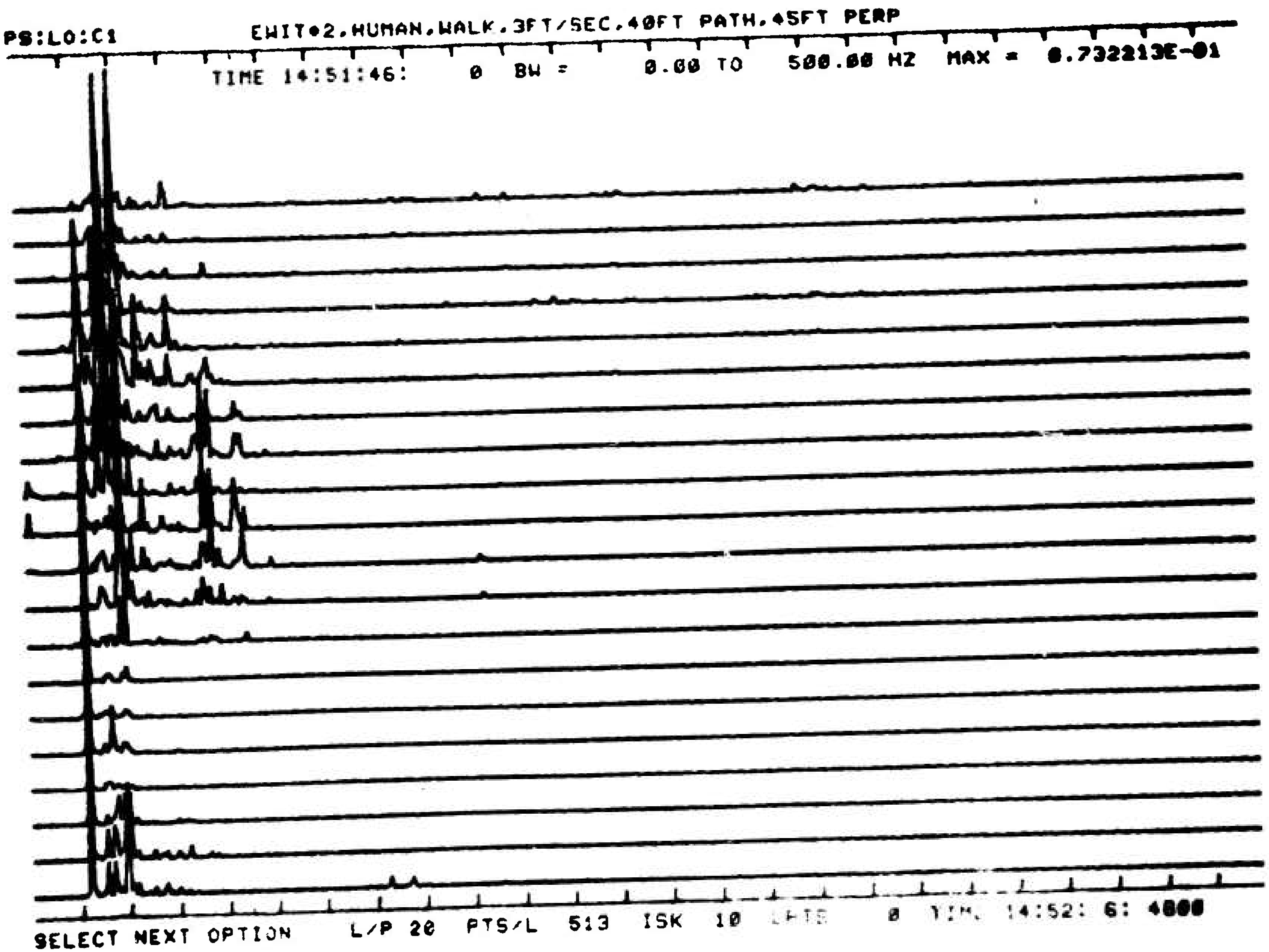

Figure 6-41. Power Spectrum of Human Walking (13" Isothermal, 5" Snow)

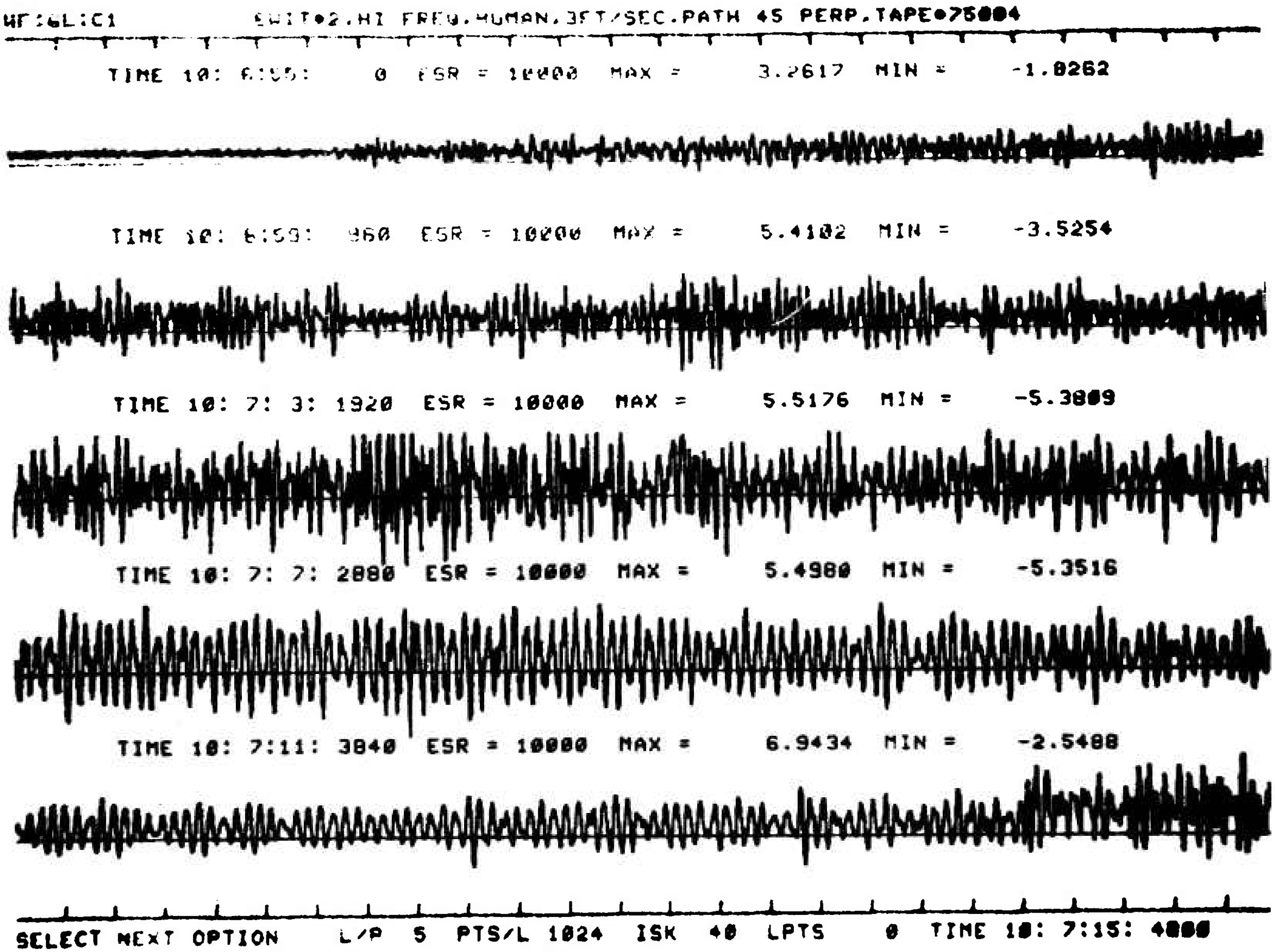

Figure 6-42. Analog Response of Human Walking (Thawed, 1" Snow)

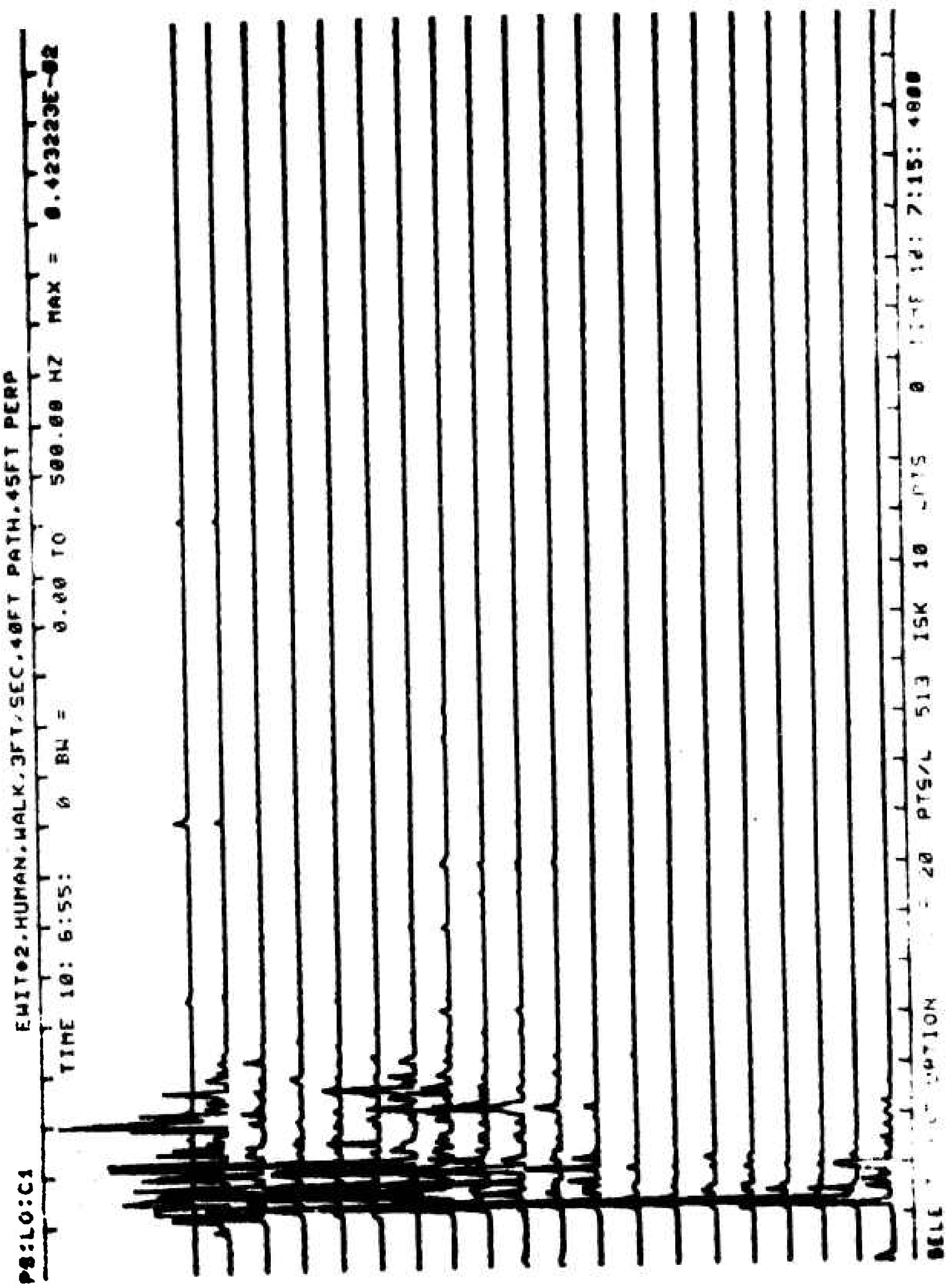

Figure 6-43. Power Spectrum of Human Walking (Thawed, 1" Snow)

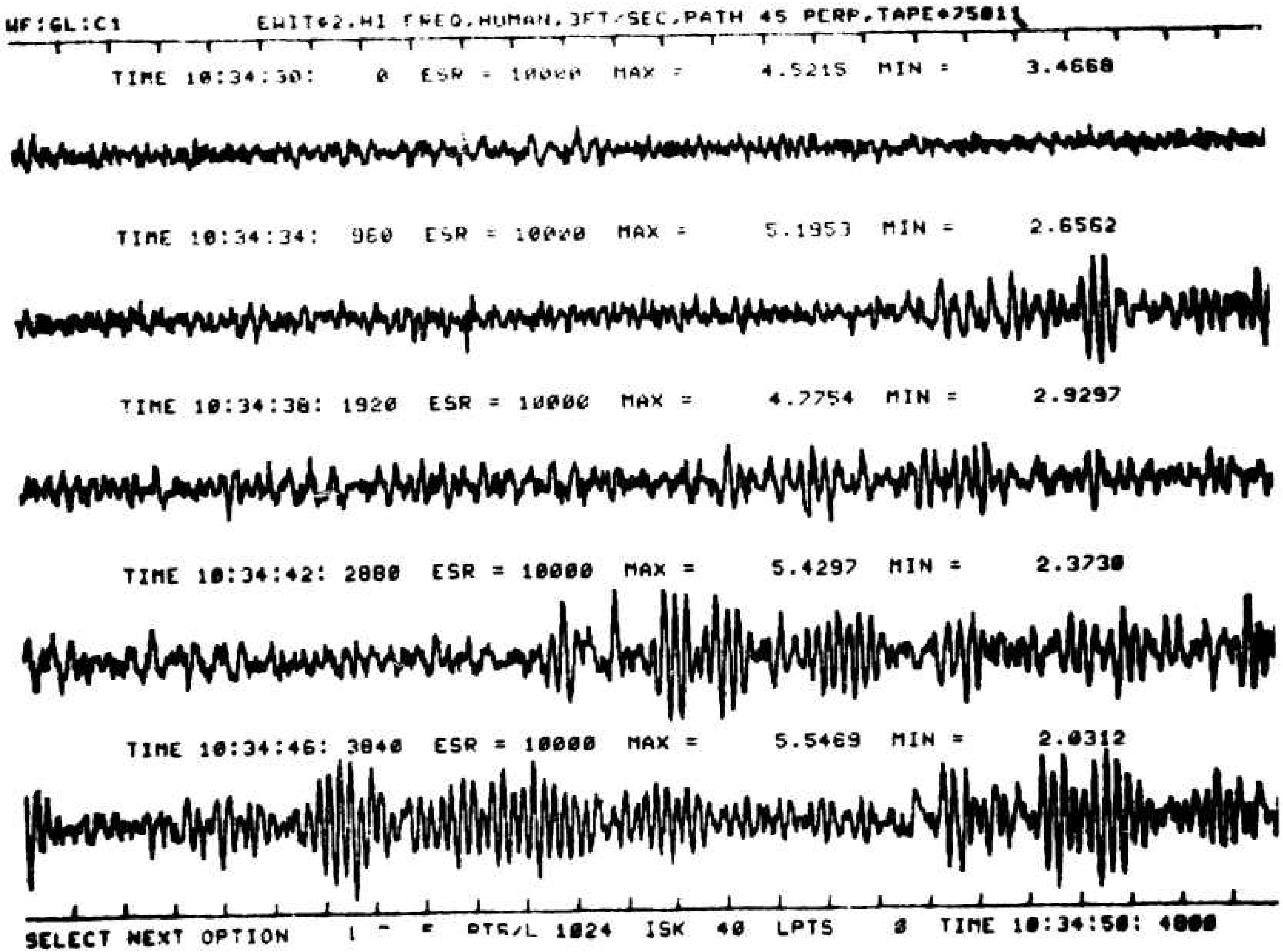

Figure 6-44. Analog Response of Human Walking (Thawed, No Snow)

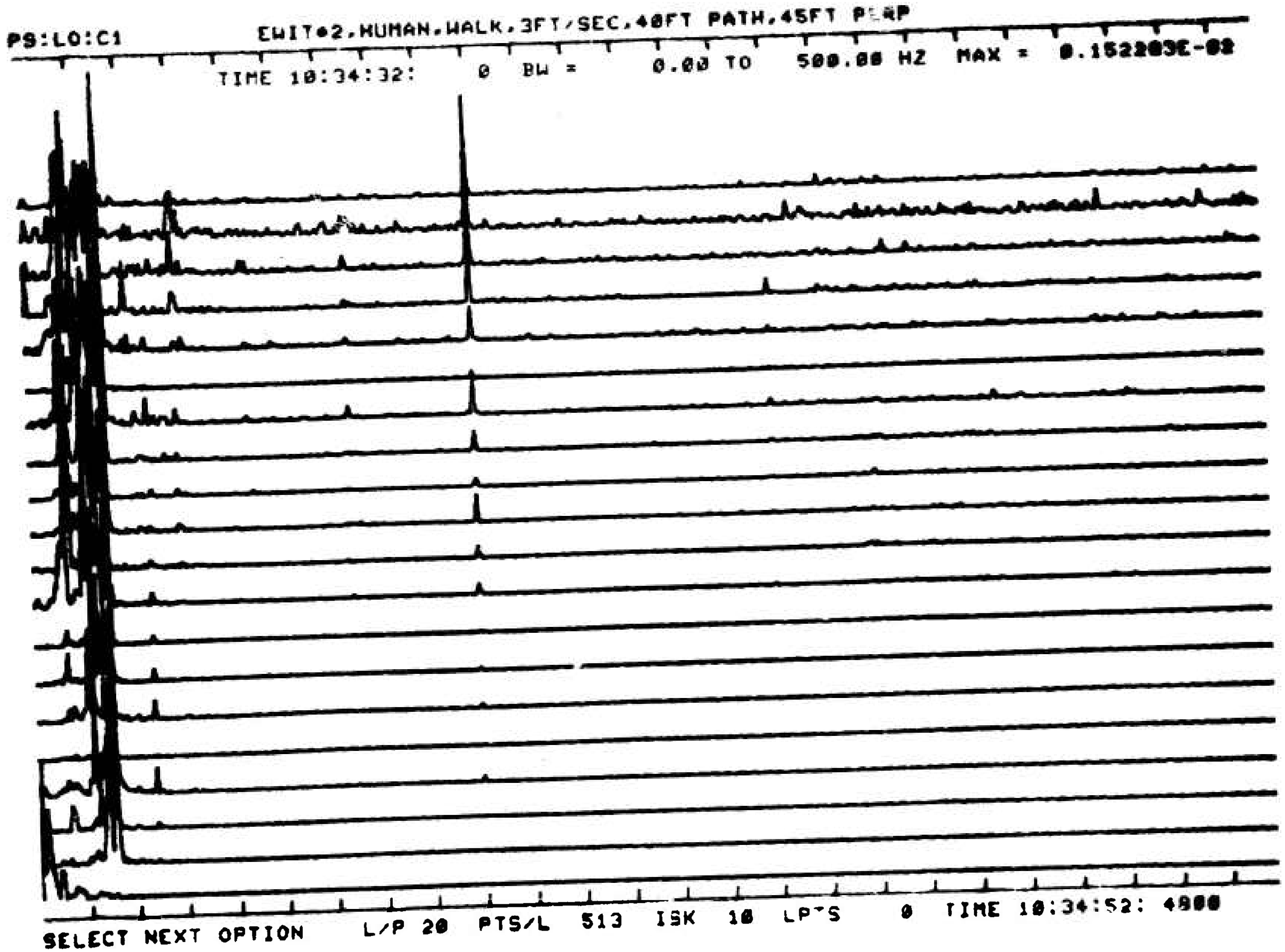

FIGURE 6-45. Power Spectrum of Human Walking (Thawed, No Snow)

One of the objectives of this evaluation, as stated in paragraph 3.3, was to study the effects of high winds on the performance of the WIT transducer. Unfortunately, this objective was not completed due to the lack of high winds during the evaluation period. Winds up to 20 miles per hour were common during this test period, a sample of which has already been included in section 6.3.8 of this report. The main effect of winds that were seen was a slight increase in the background noise level. This increase was not sufficient to interfere with signals from an intruder crossing the transducer. As stronger winds occur, they will be recorded and added to the data base.

7.0 Conclusions and Recommendations

The results of this limited test program indicate that this transducer is well suited for surveillance applications. One application would be as a listening device where the output is simply fed to a speaker. This mode is recommended wherever an operator can be used. With an operator acting as a discriminator, it is extremely easy to distinguish between various targets, such as personnel and trucks, and background noise such as aircraft, wind, and thunder. Training of an operator appears to be extremely easy and should be able to be accomplished in less than a week. It does not appear to be fatiguing to have the speaker on continuously because very little information is generated except during the time of an intrusion. Finally, practically no electronic changes would be needed to existing equipment if it were used in this mode.

A second application could be developed where this sensor acts as a complement to other sensors. This would act as a listening system as above but the speaker would not be activated until an intrusion was sensed by another sensor. At this point the speaker would be automatically turned on by the alarm signal from another sensor and a trained operator would make the decision as to the validity of the alarm.

The third application would be as a sensor with

sufficient processing electronics to make the decision as to whether the alarm is the result of a human, vehicle, or a nuisance. In this mode, however, several areas will require further investigation. These include:

a. The noise spike described in paragraph 6.3.9 which is due to thermally induced movement of the sensor. Techniques LR to deal with this problem should be investigated. Several techniques are described in the Westinghouse report[3] which may alleviate this problem. One technique would be to use the noise spike as a randomly generated self-test signal.

This self-test technique would have the advantage of including the transducer in the test function. If difficulties are encountered implementing the self-test feature, LR two other techniques are described to hopefully eliminate the noise spike all together. One method consists of periodic mechanical fixing of the wire in the tube to prevent longitudinal tension buildup and subsequent slippage. The other method, also to prevent tension buildup, would be to intentionally crinkle the center conductor wire.

b. Variance in electret potential as indicated in paragraph 6.1. One reason for the variance in the repeatability at successive stations was due to the inconsistency of the electret potential on the teflon insulation. This change in the electret potential, as shown in Figure 6-3,

is approximately 5:1. Further investigation into the manufacturing process is recommended to insure a uniform electret charge on the wire insulation. A uniform electret charge should result in a more uniform signature from point-to-point along the transducer, which would provide an improvement in detection probability and/or false alarm rate. A uniform electret charge would also eliminate unit-to-unit sensor sensitivity variations, allowing the electronics to be pre-set to a predetermined level.

c. Additional drop hammer tests. Due to the late delivery of WIT and late development of the drop hammer, impulse tests were not conducted against the WIT transducer during the winter months. These tests should be accomplished for a variety of snow depths, frost levels, and thaw conditions. The information gathered during these tests will allow us to more accurately predict how the WIT will respond in a winter environment.

An effort should also be made to collect lightning, thunder, and high wind data. Due to the lack of localized storms, very little lightning and thunder data was recorded. Also lacking was wind data above 20 mph. As soon as winds above 20 mph occur, they will be recorded and will become part of the data base.

The final recommendation would be to run a direct comparison of this transducer with current sensors deployed by the Air Force. The projected cost of this transducer

is significantly less than current production costs of present line sensors. If the capability is equal or better with this transducer then a significant cost savings could be realized.

In summary, the areas left to investigate should not inhibit the start of a pattern recognition program to develop the required processing electronics. It is recommended that this process be started and when it is completed and the electronics fabricated, a comparison between this electronics and a human discriminator should be made. The results of this comparison could be used to determine the configuration to recommend for production.

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2. "Frost Penetration Measurements at the USAF Intrusion Sensor Site, Griffiss Air Force Base, New York, 1973-74," U.S. Army Corps of Engineers, RADC-TR-75-13, Volume II. Sandia Corp., AD# B004871L

3. "Development of Enclosed Wire Intrusion Detection Transducer," Fred S. Geil and Heinz Gilcher, RADC-TR-75-247, September 1975. Westinghouse, AD# B007945L

4. "Target Properties and Signal Propagation Dynamics (U)," G.F. Pfeifer, J.H. Kipping, L.M. Bergere, RADC-TR-76-29, SECRET-XGDS. General Electric Co.

APPENDIX A

INSTRUCTION MANUAL FOR R.A.D.C. INSTALLED EQUIPMENT

Line Sensor

The line sensor is fabricated with 1/4 inch O.D. copper refrigerator tubing covered by a plastic insulating material. The electret is made up of #26 red T.F.E. teflon flex hook-up wire, which is a natural electret. The wire is pulled into the tube enclosure and the tube is purged with dry nitrogen to eliminate moisture. Both ends are immediately sealed, the preamplifier end being provided with a vacuum feed-through seal which is connected to the wire and acts as a connector. The WIT sensor is connected to its preamplifier with an ordinary swage lock tubing fitting which acts as a mechanical connector and a seal.

Preamplifier

The preamplifier, which is directly connected to and buried with the WIT sensor, is housed in a sealed stainless steel, cylindrical shaped container. A sensor cable female connection is welded to the end of this housing. At the opposite end is a removable lid with an "O" ring seal. This lid has a permanently sealed multiconductor cable fed through to permit the required power and signal lines access to the preamplifier board.

The 40 dB preamplifier circuit as shown in Figure A1, is built up on a single glass epoxy circuit board. Transistor Q1 and associated circuit components make up a 20 dB amplification stage. This F.E.T. transistor has very good low noise characteristics in addition to its high input impedance. The amplifier input is connected to a 100 meter

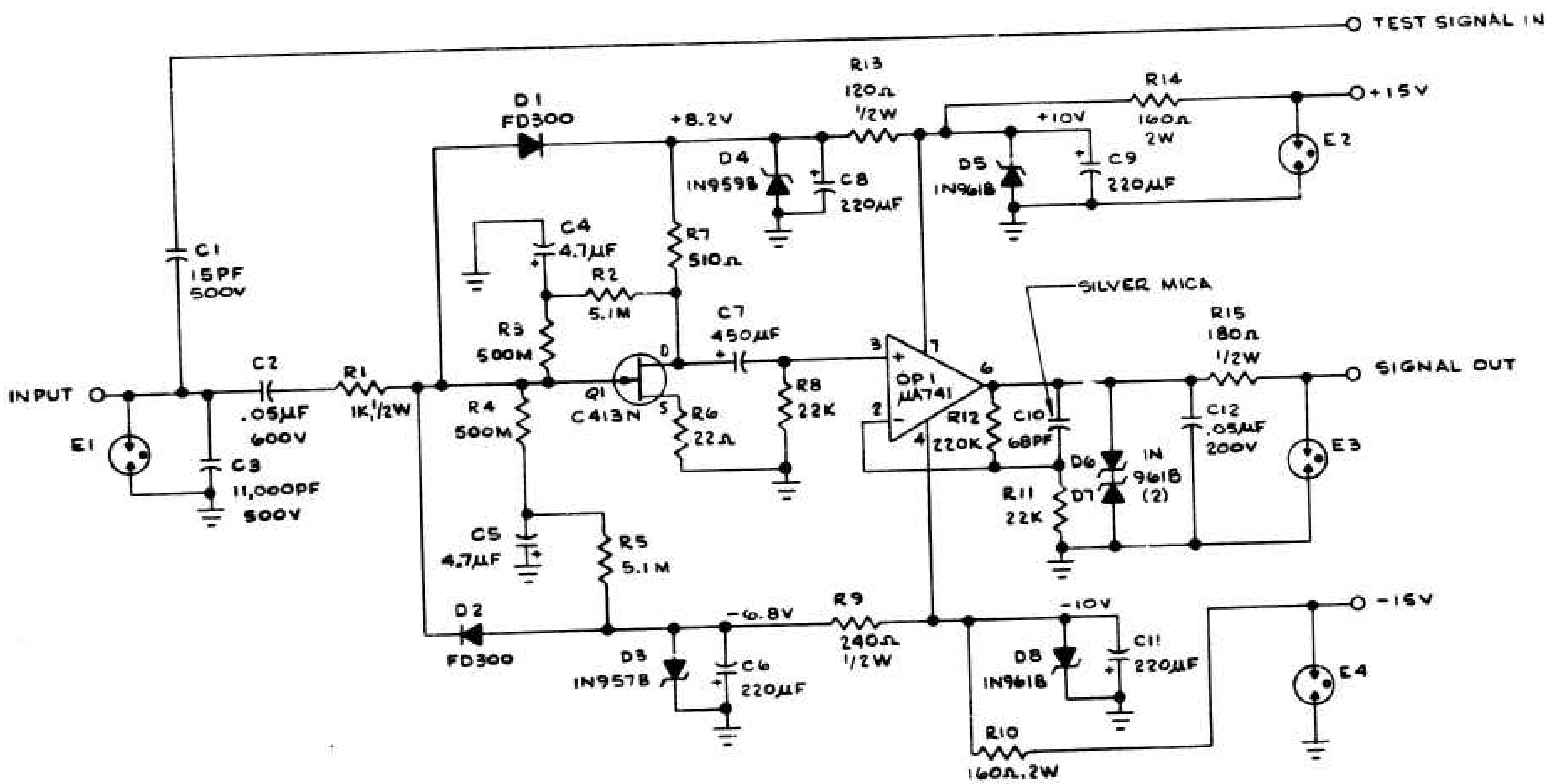


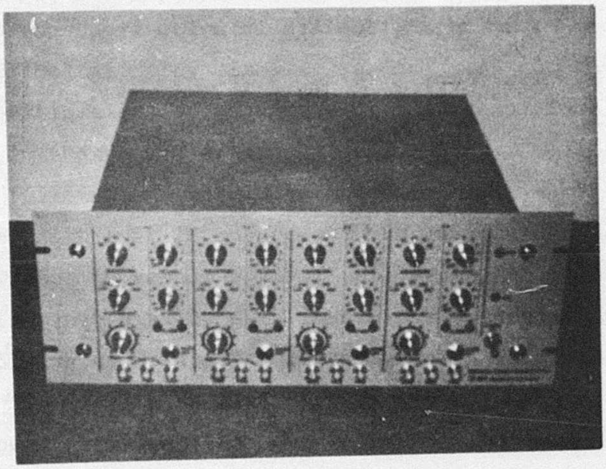
Figure A1 - Schematic diagram of preamplifier.

WIT sensor which has an approximate capacitance of 4800 pF. Capacitor C3 in parallel with the sensor has a total of about .016 μF capacitance. The D.C. input impedance of the amplifier is 250 MΩ and in parallel with .016 μF input capacitance, results in a low frequency cutoff of a little less than .05 Hz. The test signal, which is for the purpose of testing the complete system, is connected to the amplifier front end through capacitor C1. The test signal is attenuated 60 dB as a result of the voltage divider action of C1 and the parallel combination of the sensor capacitance and C3. Component E1 is a high voltage transient arrestor. Low noise, low leakage diodes D1 and D2 in combination with R1 provide additional high voltage protection to transistor Q1. Resistor R2 provides D.C. feedback to provide for unity gain at D.C. and, as a result, good bias stability. Capacitor C4 shorts the feedback signal to ground over the operating frequency range. The output from the drain is coupled to a UA741 operational amplifier which provides an additional 20 dB of gain and a low drive impedance. Two stages of decoupling are provided on both the +15 V and the -15 V bus voltages. Both power inputs and the signal output are provided with high voltage transient suppressors, E2, E3, and E4, for lightning protection. Additional protection is provided on the power buses by resistors R10 and R14 and associated zener diodes D5 and D8. The signal output has additional transient protection provided consisting of R15 and C12 and zener diodes D6 and D7. The maximum output voltage swing is about 15 V p-p. The preamplifier band pass frequency ranges from .05 Hz to about 9 kHz ; the overall voltage gain is 40 dB.

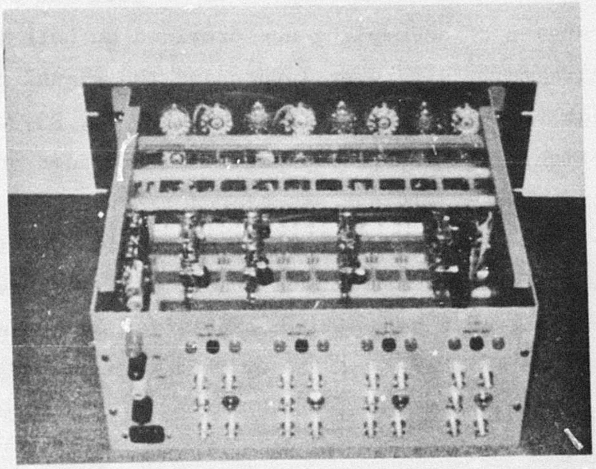
Console Functional

The instrument console for the four WIT sensor systems, as shown in Figure A2(photo), was designed for maximum operator freedom in selecting test parameters.

The front panel is divided into four separate sections, one for each sensor. Each of the four sections has the functions shown in Figure A3. The input from a preamplifier is fed into the broadband



Front



Rear

Figure A2 - Front and rear view of completed console.

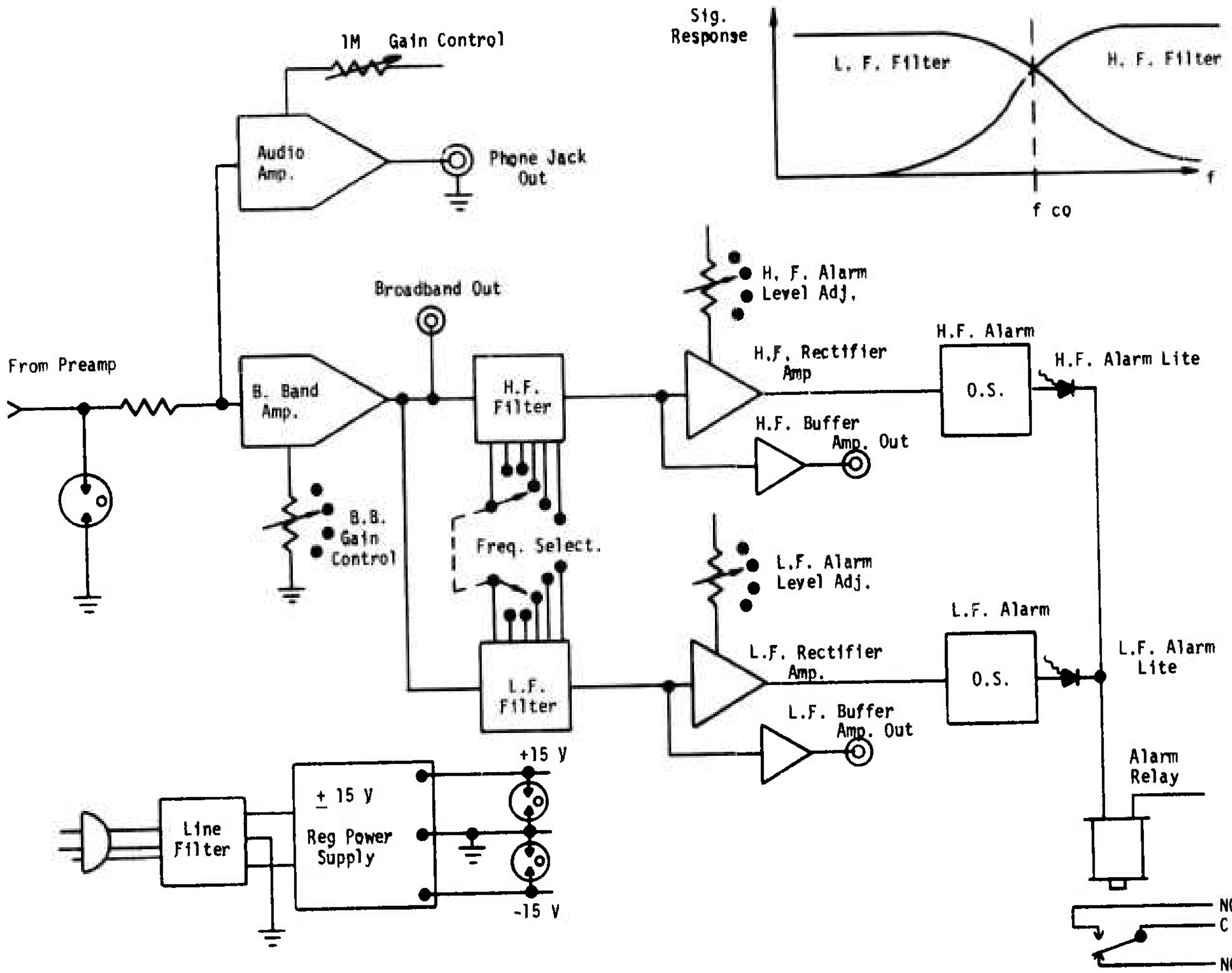


Figure A3 - Block diagram of console, one channel.

amplifier. A front panel gain selector switch provides total system gain selection in the range of 40-80 dB. The broadband amplifier bandwidth ranges from .05 Hz to 10 kHz. The amplifier output is fed to a high frequency and a low frequency filter which are controlled by a single front panel selector switch. The high frequency filter is a high pass filter and the low frequency filter is a low pass filter, both having the same cutoff frequency as shown on the upper right of Figure 3. The selector switch provides five cutoff frequency positions. These are spaced at one octave intervals ranging from 1.25 Hz to 20 Hz. The output signals from the filters are each fed to rectifier amplifiers which convert positive and negative signal excursions to negative excursions only, and also provide low impedance drive capability. Separate buffer amplifiers are provided for monitoring filter outputs directly. The negative going signals from the rectifier amplifiers are fed to one shot-multivibrators. When the negative signal amplitude exceeds -10 V, the appropriate one-shot is tripped and remains on for about a 0.5 second duration. The one shot multivibrator outputs are connected in "or" logic and actuate an alarm relay. Light emitting diodes located on the front panel are connected in series with the multivibrator outputs to provide visual alarm indications. Connections to the relay contacts are provided on the back panel of the console.

The high and low frequency alarm level selectors located on the front panel provide a selection of eleven positions including an off position. These alarm level selector switches control voltage dividers which change the D.C. output biases on the rectifier amplifiers and as a result the required signal amplitudes needed to trip the alarm one shot multivibrators.

An audio amplifier was added to each WIT channel in order to use the system in a listening mode. The audio amplifier has a bandwidth of about 100 Hz to 10 kHz. The total gain range, including the preamplifier, is 40 to 80 dB and is controlled by a gain potentiometer located on the front panel. A phone jack, located on the front panel, is also provided for audio headset listening.

Console Circuits

An electronic circuit diagram of the console is shown in Figure A4. There are four identical electronic circuit boards and associated circuits. All of board #1 circuitry is shown enclosed within the dashed lines. The controls are all located on the front panel. Relay and cable connections are located on the rear panel.

The input to each channel is protected with a high voltage Siemens gas arrestor. In addition, Resistor R1 and zener diodes D1 and D2 provide for additional signal amplitude limiting. From here the input signal is coupled through capacitor C1 into the broadband amplifier, which is made up of IC-2 and associated components. Note that the broadband gain switch and associated resistors are part of this amplifier.

The audio amplifier input also takes advantage of the transient signal limiting at the broadband amplifier input. The input signal is coupled through capacitor C10 into the audio amplifier. This amplifier is made up of IC-1 and associated components. The output of the audio amplifier is connected by way of a current limiting resistor R9 to a phone jack.

The output of the broadband amplifier connects to the high frequency filter made up of capacitor C12 and the components associated with the high frequency response adjust portion of the selector switch. The broadband amplifier also connects to the low frequency filter made up of resistors R11 and R22, capacitor C3, and the components associated with the low frequency response adjust portion of the selector switch.

The output of the high frequency filter is fed to a signal limiting circuit made up of resistor R12 and zener diodes D3 and D4. One output of the limiting curcuit feeds into emitter follower buffer stage made up of transistor Q2 and associated components. The other limiting curcuit output is connected to the high frequency rectifier amplifier which is made up of IC-3 and associated components. At the input to this amplifier are diodes D5 and D6 which split the input

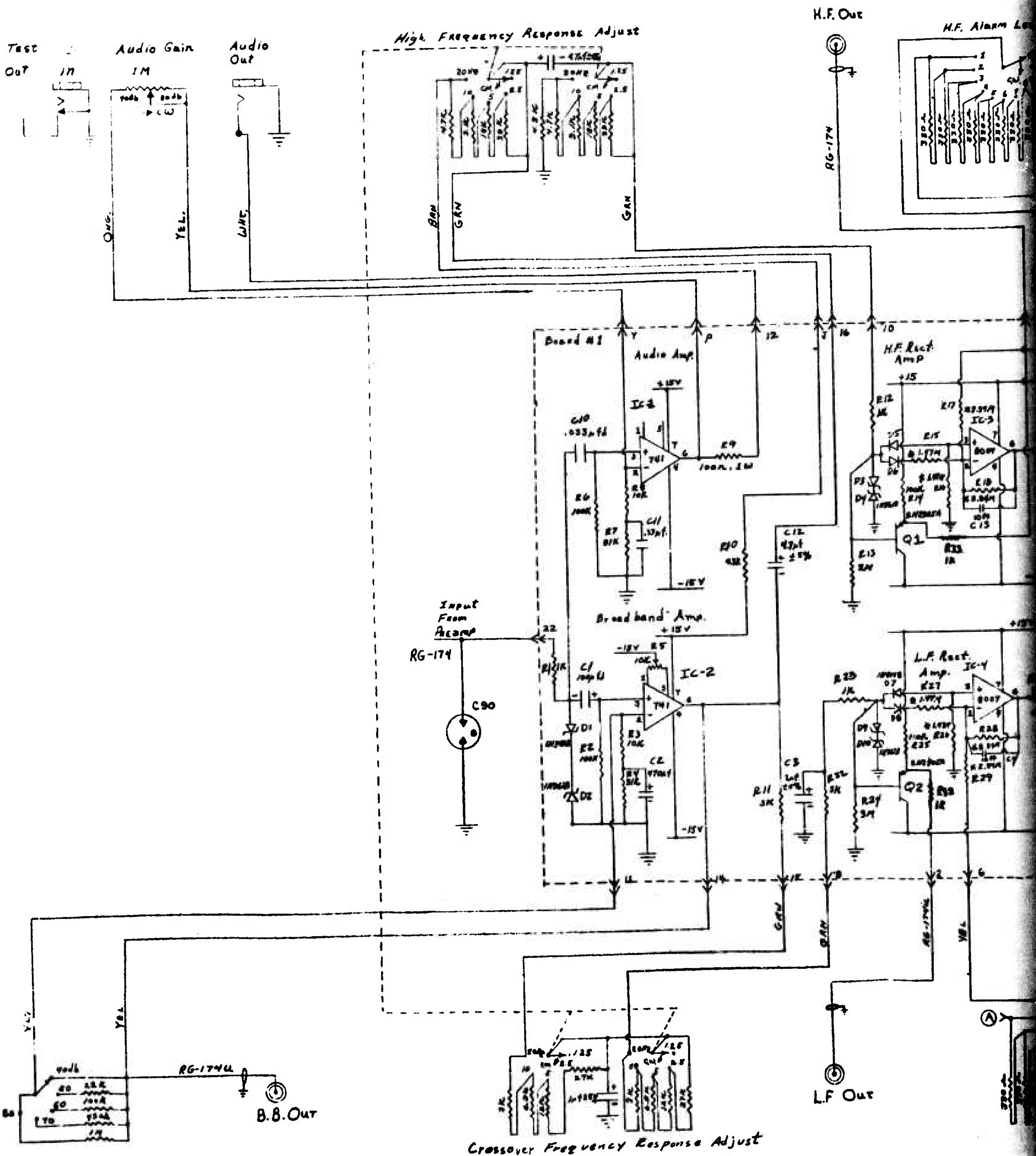
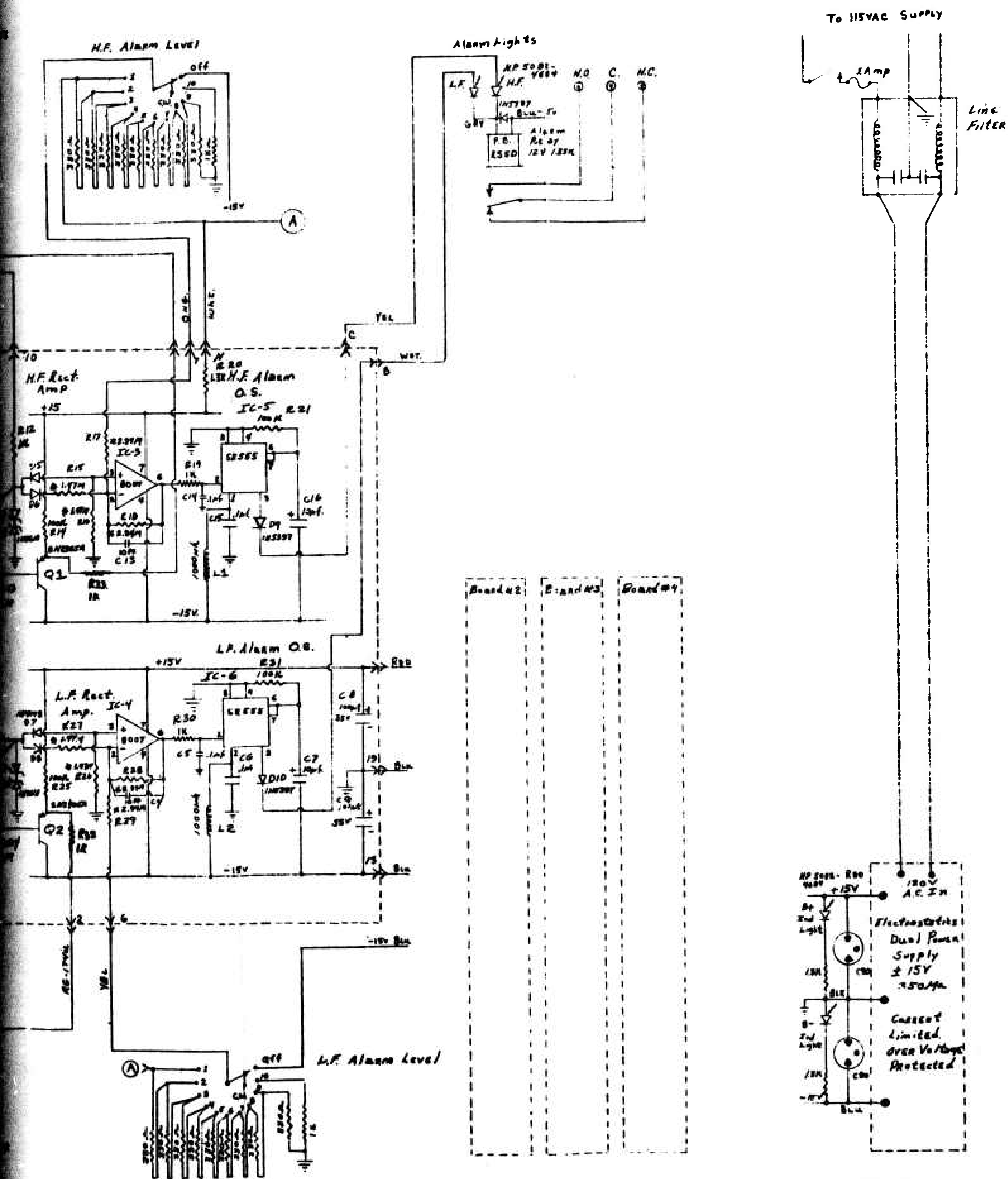


Figure A4 - Schematic Diagram of Console.



Note:
* ±1% Tolerance

This is only copy available.

Console.

signal to the two amplifier inputs. Diode D5 permits only negative going input signals to pass, while D6 only permits the passage of positive signals. Since the input to the IC amplifier at pin 3 is noninverting and since the input to pin 2 is inverting, the resulting output at pin 6 appears rectified. Various precision resistors are arranged to provide for the proper bi-polar scaling. The amplifier gain is set at two, which means that if a six volt peak to peak signal is fed to the input, the resulting rectified output would be a six volts peak signal.

The high frequency alarm level switch and the associated resistors form a voltage divider network. The switch wiper connects scaling resistor R17 to the divider network providing a positive D.C. bias voltage through R17 to the amplifier inverting input. This results in offsetting the normal zero D.C. output to a negative D.C. output which varies according to the selector switch setting. As a result, when the high frequency alarm level switch is set to position 10, the minimum positive voltage, the signal required to trip the high frequency alarm is maximum since the trip voltage is set at about -10 V. The off position of the selector switch connects a negative 15 V to the rectifier amplifier. This causes the amplifier output to go into positive saturation and even a maximum input signal cannot trip the high frequency alarm.

The output of the high frequency rectifier amplifier feeds into the high frequency alarm one-shot multivibrator. This one shot shown as IC-5 is connected with the positive power bus at ground and the negative bus at -15 V. This establishes the signal voltage trip level at -10 V. The on time of the multivibrator is established by resistor R21 and capacitor C16.

The low frequency rectifier amplifier and alarm one-shot multivibrator circuits are identical in all respects to their high frequency counterparts.

The outputs of the one-shot multivibrators are on pin 10 through blocking diodes D9 and D10. These outputs are connected to high frequency and low frequency alarm lights and then to the alarm relay.

The instrument is powered by a single dual voltage regulated power supply. The positive and negative supplies have a L.E.D. indicator light connected across their outputs. High voltage surge arrestors are also provided across both supplies. The 115 V A.C. power input is provided with a dual line filter to block out power line noise.